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The drawing on the cover is of the bark Endeavour, *which, commanded by Captain James Cook and carrying a number of scientific workers, was sent out by the British Admiralty in* 1768 *to chart the South Pacific Ocean and observe the transit of Venus*

CONTENTS

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ENDEAVOUR

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Science, history, and civilization

The vast expansion of science in the present century, with its accompaniment of an ever-increasing specialization, has led many scientists to develop a growing interest in the history of science. It is as though the constantly narrowing field of their own work has led them to seek mental refreshment in a study of the vast and variegated tapestry of history to which they are adding their individual fragments. This awakening to the value of historical science as a corrective of scientific specialization has shown itself in the foundation in many countries of societies and journals devoted to such studies; moreover, the movement has received the seal of academic recognition. As a consequence, there is now a widespread opinion that historical science offers one of the best ways of opening up a wider horizon for followers of the arts no less than for those of the sciences, providing them in so doing with a common intellectual interest and meeting-ground. In both fields, indeed, the history of science becomes a dominant theme in the history of civilization. The publication of a work on historical science by a professional historian is therefore a significant happening that calls for something more than a cursory reference in journals devoted to science.

The University of Cambridge has taken a noteworthy part in promoting the study of historical science. In 1937, the general board approved a series of weekly lectures on the history of science, delivered throughout the session by experts on various themes, and open without fee to all members of the university. In 1944, the movement was greatly stimulated by the presentation to the university of the Whipple collection of rare scientific instruments and books, of great historical value. At the inaugural ceremony, Sir Henry Dale, then President of the Royal Society, emphasized the importance of the study of the history of science, both by scientists who needed to appreciate the human side of their work, and also by students of classics, history, and theology. Similar activities have been fostered in other academic centres, both in Britain and abroad. For a recent undertaking at Cambridge, the history of science committee invited the professor of modern history in the university to deliver a course of a dozen lectures on the history of scientific activity in modern times, viewed as a continuous process of development. This task he fulfilled with distinction.

In his admirable lectures, recently published,[1] Professor Butterfield stresses above all the part played by the sciences in the evolution of western civilization; his exposition makes it clear that the history of science has contributed many of the threads woven into the unbroken web of human history. Taking the broad view of the historian, he states his opinion that the scientific revolution, resulting in the eclipse of scholastic philosophy and in the destruction of Aristotelian physics, 'outshines everything since the rise of Christianity and reduces the Renaissance and Reformation to the rank of mere episodes, mere internal displacements, within the system of medieval Christendom.' Indeed, he considers that this remoulding of scientific thought 'looms so large as the real origin both of the modern world and of the modern mentality that our customary periodization of European history has become an anachronism and an encumbrance.' This outspoken opinion, foreshadowing a devaluation of certain historical currencies, will find ready acceptance among historians of science.

The dawn of the seventeenth century saw also the dawn of modern science, but the ultimate roots of the scientific revolution of that era strike

[1] H. Butterfield, *The Origins of Modern Science*, 1300–1800, Pp. x + 217. G. Bell and Sons Limited, London. 1949. 10s. 6d. net.

back a long way, even far beyond classical Greece. The literary transmission to the western world of the scientific knowledge of the ancient civilizations, reaching its culmination at the time of the Renaissance, brought about a saving of centuries of effort: 'in the middle ages men found themselves endowed with an explanation of the physical universe and the workings of nature which had fallen upon them out of the blue . . . and they were infinitely more the slaves of that intellectual system than if they had actually invented it themselves.'

The key opening the gates of the scientific revolution is to be found in the law of inertia, the recognition of which ultimately led to the abandonment of an imagined universe actuated by invisible hands in favour of a new model having an automatic mechanism of a clockwork type; but nearly a century and a half had elapsed after Copernicus had published his great work, *De Revolutionibus Orbium* (1543), before Newton was able to effect his grand synthesis of the underlying dynamical and gravitational problems in his *Principia* (1687). This correlation of mechanics and astronomy, of motion in the earth and in the skies, lies at the very core of the scientific revolution of the seventeenth century. Similarly, in the realm of biology, Vesalius' *De Fabrica* (1543), the foundation of anatomy, published in the same year as the master-work of Copernicus, was followed in due course by Harvey's revolutionary thesis, *De motu cordis* (1628). A new era had opened in the study of living organisms.

There was a celebrated Frenchman who took care that the new views should become generally known. Fontenelle, nephew of Corneille, and in Voltaire's opinion the most universal genius of his day, became an early and successful popularizer of science. Living to within a month of his centenary (1657–1757), this remarkable man spanned the passage from the scientific revolution of the seventeenth century to the 'age of reason' of the eighteenth. Professor Butterfield describes his *Entretiens sur la pluralité des mondes* (1686) as 'the first work in France which made the discoveries of science clear, intelligible, and amusing to the general reading public.' Science stands urgently in need of such expositors at the present day, for it has never been so important as it is now for the ordinary man to know what science is doing, and to understand the implications of the new knowledge and the powers that it brings.

It is a striking feature of the history of science that the scientific revolution of the seventeenth century did not reach chemistry. It is often held that the misleading theory of phlogiston was mainly responsible for the postponement of the chemical revolution until late in the eighteenth century, but, as a recent writer has emphasized, the delay was due rather to lack of knowledge of the different kinds of gases and of the technique of handling them, and to the rudimentary views that were held at that time concerning chemical change. There were 'no clues to the composition of air, fixed air, or water; and, while air is the food of fire, fixed air and water are the products of combustion of all organic materials.'[1] The work of Black, Scheele, Priestley, and Cavendish, in the second half of the eighteenth century, inaugurated a new era by preparing the way for a recognition of the chemical nature of air and water. Then, as so often in the history of science, a point was reached at which all the necessary data had been collected to enable a tremendous step forward to be made.

That great historian of science, George Sarton, has recently written: 'It is true that most men of letters, and, I am sorry to add, not a few scientists, know science only by its material achievements, but ignore its spirit and see neither its internal beauty nor the beauty it extracts continually from the bosom of nature. . . . A true humanist must know the life of science as he knows the life of art and the life of religion.'[2] Professor Butterfield has shown himself to be a true humanist.

[1] J. Read, *Humour and Humanism in Chemistry* (London, 1947).

[2] G. Sarton, *The Life of Science; Essays in the History of Civilization* (New York, 1948).

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The steady-state theory of the expanding universe

W. H. McCREA

According to the steady-state theory, the creation of matter is proceeding at the same rate now as in the past. The present article reviews the difficulties in previous cosmologies which the new theory appears to overcome, and indicates its promise of success in explaining certain general features of the universe, such as the formation of galaxies and systems of galaxies.

1. The steady-state theory of the expanding universe was propounded by H. Bondi and T. Gold [1] in 1948. Their suggestion is that the creation of matter is a continuing process operating at the same statistical rate at all epochs, a statistically constant density being preserved by the dispersal of matter known as the expansion of the universe.

It is too soon to claim that any crucial consequence of this hypothesis is definitely established by available observational data. It does, however, appear to overcome serious difficulties encountered by previous theories when confronted with these data. It promises also to afford a satisfactory account of the formation of galaxies and systems of galaxies, a type of problem about which the previous theories have little information to offer.

THE EXPANDING UNIVERSE

2. *Cosmological principles.* Theories of the universe, in the main, deal in the first instance with models in which all the contents are regarded as 'smoothed out': the concentrations of matter into stars, galaxies, etc., in the actual universe are replaced by a continuous distribution of 'fluid' in the model, the motions of these bodies being represented by the hydrodynamical behaviour of the fluid. The distribution of radiation is treated similarly. The models are also required to be homogeneous and isotropic (uniform). Homogeneity implies that a (fundamental) observer A, moving with the fluid, forms, at any instant in his experience, the same picture of the universe as does another such observer B anywhere else in the universe at some instant in B's experience. Unless the universe is in a steady state, this implies the existence of cosmic time, a particular instant in cosmic time being that at which all fundamental observers see the same picture. What is homogeneous is in fact the whole of space at any instant of cosmic time. Isotropy means that every fundamental observer sees the universe as radially symmetric about himself.

The hypothesis of homogeneity is also called the cosmological principle (CP), but, since it refers to space only and not to time, we may call it the restricted CP. A universe that is homogeneous in time, i.e. in a steady state, as well as homogeneous in space, is said by Bondi and Gold to satisfy the perfect CP. It follows, not that nothing happens in such a universe, but that the same things are happening all the time.

As regards the actual universe, surveys of the sample accessible to observation are considered to show that it is in fact spatially uniform, when regarded statistically on a large enough scale. Whether it is in a statistically steady state is the major problem before us. The solution cannot be had directly from observation; as we shall see, the interval required for a significant statistical test would be of the order of 10^9 years. The only hope of a solution lies in the comparison with observation of various predictions based on the possible alternative hypotheses.

3. *Model universes* [2]. The first theoretical model of the universe was that proposed by Einstein in 1917. At that time it seems to have been taken for granted that the universe as a whole must be in a steady state, at any rate mechanically, which is all that concerns a purely gravitational theory. Einstein noted that his original gravitational equations admitted no static homogeneous solution. A static solution was possible only for the equations modified by the so-called 'cosmical terms' having as coefficient the mysterious cosmical constant λ. The model which then resulted is well known, being that which led to discussions of 'finite but unbounded space' and 'seeing round the universe.'

The only other uniform steady-state solution is

that discovered about the same time by de Sitter. This is a non-static solution of Einstein's modified equations. But, since those equations require the conservation of matter, the matter in the universe as a whole can be in motion, and yet have a density that does not vary with time, only if the density is zero. So de Sitter's is an empty universe. As a model it could, however, be regarded as a possibly instructive limiting case. As such it was of great significance, for it first served to predict the recession of the galaxies with speeds proportional to their distances.

Non-steady uniform models were then studied, first by Friedmann (1922) and Lemaître (1927). The immediate result of their work was that it enabled Eddington to deduce that Einstein's static universe is unstable in regard to sorts of disturbance which certainly occur in the actual universe. Consequently the universe is not in a static state. Its mean density is not zero, and so neither is it in the only other (de Sitter) possible steady state allowed by relativity theory.

Relativists, therefore, studied exhaustively all classes of non-steady uniform solutions of Einstein's equations, both with and without the cosmical terms. All solutions predicted the phenomenon of mutual recession of fundamental observers with speed proportional to distance (at any rate to a first approximation), i.e. the expansion of the universe.[1]

While these theoretical conclusions were being reached, observational evidence for the recession of the galaxies was also being amassed, and Hubble's law, that the speed of recession is proportional to the distance, was emerging as an empirical result. So the conclusions were hailed as a triumph of the relativity theory.

An element almost of disillusionment was then introduced by Milne's suggestion [3] that the recession may be ultimately no different from the purely kinematic phenomenon of the dispersal of, say, a cloud of gas in space or of a handful of beads spilled on the ground. It can be shown, however, that this actually is the phenomenon studied in the relativity treatment, subject to the mutual gravitation of the parts of the dispersing material and to the uniformity condition.

Milne himself followed up his suggestion by developing his system of kinematic relativity [4]. As concerns models of the universe, this theory yields analogues of certain of those given by general relativity. It thereby provides an alternative treatment of the same physical situations.

The nature of these situations was further clarified when Milne [5] discovered the Newtonian analogue in one case, and Milne and McCrea [6] proceeded to show that Newtonian analogues exist for all the relativity models.

4. *Physical interpretation.* Some explanation of this last result is needed. Consider ordinary Newtonian space and time (t). Let O be any fundamental observer, R any point of space such that $OR = \mathbf{r}$, ρ the density of matter at R, and $\mathbf{v}$ its velocity. As is easily shown, the restricted CP requires that $\mathbf{v}$ be a scalar multiple of $\mathbf{r}$, say $\mathbf{v} = V\mathbf{r}$, and that ρ and V be independent of $\mathbf{r}$.

O certainly sees this 'universe' as spherically symmetrical about himself. If he then makes a straightforward application of Newtonian gravitation for a spherically symmetrical distribution of mass, and uses also the equation of conservation of matter, he obtains differential equations for ρ and V as functions of t.

The equation for V is not only analogous to, but also formally identical with, the corresponding equation for the relativity models with $\lambda = 0$. The theories differ only in 'geometrical' aspects. The three types of model arising in the relativity treatment are then revealed as those that any observer O would describe by saying that the material at distance r has more than, the same as, or less than the Newtonian 'velocity of escape' from that within distance r of himself.

Finally, the relativity equations with $\lambda \neq 0$ are found to be reproduced by the Newtonian model if, in addition to Newtonian gravitation, O assumes the existence of a force of 'cosmical repulsion' $\frac{1}{3}c^2\lambda\mathbf{r}$ (where c is the velocity of light and the coefficient $\frac{1}{3}c^2$ is introduced merely to match the relativity practice) [7]. It can be shown, moreover, that a term of this form is the only modification of Newtonian gravitation that can preserve conformity to the restricted CP.

Thus we know in easily appreciated terms the physical situation represented by any particular model, and that the physical phenomena are essentially the same whether the model is provided by general relativity, kinematic relativity, or Newtonian theory (which we shall call the 'dative' theories). It turns out, further, that the predicted observable characteristics of any model and its analogues in the different theories differ only in the second or higher orders as between one theory and another. This is embarrassing if we want to

[1] Einstein's equations being reversible in time, any expanding solution gives also a contracting one by simply reversing the sign of the time-variable, but the latter need not be considered here.

decide observationally between the relative merits of the theories, but it has the advantage that comparison with observation is not too much affected by mathematical differences between the treatments. If we encounter serious difficulties in interpreting the observations according to any one of the theories, such difficulties are almost certainly owing to inadequacies in the physical concepts, and are not to be overcome merely by replacing one mathematical treatment of those concepts by another.

5. *Comparison with observation.* Hubble [8] has thoroughly investigated the fitting of a relativistic model to the observational data. He finds the model that gives the best fit (subject to uncertainties in the reduction of the observations) to be highly unplausible on general grounds.

So impressed was Hubble by the impossibility of obtaining satisfactory quantitative agreement that he felt compelled to question the basic interpretation of the spectral shifts of the galaxies as velocity-shifts. But this solution of the difficulty is not readily acceptable, because no other interpretation is forthcoming[1] and also because the usual interpretation gives qualitatively the effect predicted by all the theories; it would be strange if the interpretation were then only partially applicable.

6. *Further difficulties.* Accepting the usual interpretation of the spectral shifts, Hubble's law is (to a sufficient approximation):

Speed of recession of a galaxy
$$= 1{\cdot}8 \times 10^{-17}\ \text{cm/sec} \times \text{distance in cm} \quad (1)$$
Therefore, if the galaxy has moved with uniform velocity, its distance was zero $(1{\cdot}8 \times 10^{-17})^{-1}$ sec, or about $1{\cdot}8 \times 10^9$ years ago, whatever its present distance.

This is the crudest possible estimate of the age of the universe. Every model of the sort already discussed leads, however, to approximately the same inference: that about 2×10^9 years ago all the matter in the universe was closely packed together (or else was then in the state of an Einstein static universe in which no previous evolutionary process had occurred).

Now the age of the oldest rocks on the Earth is known to be itself about 2×10^9 years. Until recently, the view was that all the stages in the evolution of the Galaxy, before that when the Earth was formed, could have been rushed through in much less than 10^9 years in the highly congested state in which the universe was inferred to be at the epochs concerned. So it was not found strange that the age of the Earth and that of the whole universe should be the same to a first approximation. Indeed, this and certain somewhat similar results were taken as generally favourable to the inferred age of the universe.

According to recent ideas concerning stellar evolution, on the other hand, the ages of the oldest stars in the Galaxy are estimated to be about 5×10^9 years. We are reverting, in fact, to the common-sense view that the Earth is considerably younger than a good many stars. The numbers quoted happen to be ones that are not susceptible to much revision within the framework of the theories concerned. So we have to conclude that the ordinary theory of the expanding universe fails to provide sufficient time for the evolution of its contents.

Other difficulties are metaphysical. The first is that the dative theories admit a variety of theoretically possible models of the universe. But, in the case of the entire universe, there is no sense in which any but one system is physically possible: a wholly satisfactory theory ought to yield only a unique model (granted that any theory of a unique system is conceivable).

In the second place, as emphasized by Bondi and Gold, physical laws are formulated on the assumption that the circumstances to which they apply are reproducible to an unlimited extent. This can hold good in a changing universe only if the 'laboratory' where the required circumstances are considered to be reproduced may legitimately be regarded as isolated from the remainder of the universe. If we accept Mach's principle that the properties of any portion of the universe are determined by the contents of the whole universe, this last condition cannot be satisfied. On this view, the meaning of physical law in a changing universe thus presents grave difficulties. Such difficulties may need to be resolved. But we can at least see if the need ever arises: we must fully explore the possibility of a steady-state universe.

7. *Time-scales.* A conceivable escape from some of the difficulties we have mentioned is provided by Milne's use of two time-scales. In his development of kinematic relativity he is led to employ an alternative measure τ proportional to the logarithm of the cosmic time t. So the 'epoch of creation $t = 0$ becomes on the τ-scale $\tau = -\infty$.' He [10] ultimately concludes, 'It thus appears that the paradox into which contemporary physics is led in discussing the age of the universe . . . is due to confusion of the two

[1] Reference should, however, be made to Milne's views on this problem [9].

scales of time. . . . Statements involving Newtonian mechanics, or Newtonian gravitation, are usually made in terms of the τ-scale. Statements involving . . . photons, or the electromagnetic theory of Maxwell, involve the *t*-scale.'

The notion of two time-scales occurs also in Dirac's [11] approach to the same problems, but his transformation differs from Milne's.

It thus appears that the dative theories are unacceptable without some such treatment of the time-variable. But hitherto the notion has gained little general favour. Once again, we want to see first if the need for it really does arise.

COSMOLOGY AND CREATION

8. *Creation.* All previous theories assume the conservation of matter: they treat matter as 'given'[1] and avoid any consideration of its creation. As Hoyle [12] remarks, this is permissible provided all matter was created in the remote past, but not if its creation is a continuing process.

The question whether matter is being created at the present time is independent of cosmological theory. But, if creation is in progress, the rate must be so small as to offer no prospect of observing the process directly. It could be studied only in relation to the large-scale behaviour of the universe.

What has been said about the dative theories leaves little hope that their apparent inadequacies can be remedied by any modified treatment of space, time, and gravitation. That being so, their inadequacy must lie in their treatment of matter.[2] But all they assume about matter itself is that it is conserved. So there is a presumption that this postulate is invalid. Also, any fresh investigation of the possibility of a steady-state universe is in fact the investigation of the effect of abandoning this postulate. Otherwise the steady state would be incompatible with the 'expansion.' Thus the effect of all the foregoing discussion is that the possibility of continuing creation must now be considered.

The possibility has received some earlier consideration. In a well-known passage, Jeans [13] conjectured that the centres of galaxies might be places where matter is 'poured into our universe.' In a preliminary version [14] of his 'new basis for cosmology,' Dirac inferred a rate of creation of protons and electrons proportional to *t*. But he later [11] recast his formulation so as to be consistent with the conservation of matter. At the same time he remarked that 'there is no experimental justification for this assumption' of conservation: he regarded 'a spontaneous creation . . . of matter . . . as not to be worth considering, unless a definite need for it should appear.' Bondi and Gold [1] and Hoyle [15] have stated a strong case for this need, and have been the first to relate the possibility to general problems of astrophysics and cosmology.[3]

9. *Creation process.* In constructing a theoretical model universe in which matter is continually being created, corresponding to the earlier dative models, the creation process, like all the other features, is treated as smoothed out in space and time. The model will thus yield conclusions that are independent of details of the creation process.

It is convenient, however, at this stage to state what process is actually envisaged. The authors quoted suggest that:

(*a*) It is the spontaneous creation of *hydrogen atoms* (or of protons and electrons, or neutrons, the first resultant of which would be atomic hydrogen). This is because hydrogen is the simplest and most abundant element, and astrophysical evidence indicates that all other elements have been synthesized from hydrogen.

(*b*) It is random in space, being independent (to a first approximation at least) of local physical conditions. Thus it is not associated with existing concentrations of matter. This is because processes of condensation and accretion appear to be more fundamental in astrophysics than the reverse processes.

(*c*) Newly created matter is statistically at rest relative to its cosmical neighbourhood.

As described by any observer it must therefore possess the characteristic velocity of recession which he associates with its position.

One may remark that there can be no causal treatment in a physical sense of true creation. This is almost a matter of definition. If the creation of matter is caused, as is conceivable, by existing physical conditions, then the true creation

[1] Hence my venturing to term them 'dative' theories.

[2] This expresses the situation in ordinary physical terms. In the language of relativity theory, we should say that the existing field-theory is in need of revision, but we could still say that this is particularly so in regard to the conservation properties deducible from the field-theory.

[3] P. Jordan has independently concluded that it is necessary to postulate the continuing creation of matter. An account [19] of his ideas, more accessible than that in which they were originally published, has appeared since the present article was written. Jordan's formulation is, however, in less conformity with other current astrophysical theories than that of the authors mentioned above.

is of those conditions, and we should not try to give a physical theory of that creation. But we are here regarding the creation of matter as itself spontaneous, i.e. as something 'given' and not to be treated causally. We can assume that the immediate results of the creation process may be treated by probability methods, as are other spontaneous processes in atomic physics.

10. *Model universe with creation.* In order to have a definite model on which to base further discussion we provisionally accept the perfect CP. Also, we shall use Newtonian space and time, since the earlier work serves to show that this should be adequate to yield first approximations to observable relations.

The first paragraph of section 4 still holds good, since the restricted CP is included in the perfect CP. But the latter further requires the universe to be in a steady state; so ρ, V must now also be independent of t, i.e. they are universal constants (and we shall take them to be positive).

The rate at which matter is flowing out of the sphere of radius $r = |\mathbf{r}|$ is $4\pi r^3 \rho V$ per unit time. But the perfect CP requires the mass in this sphere to remain steady, i.e. it requires matter to be created at the rate μ, say, where

$$\mu = 4\pi r^3 \rho V / \tfrac{4}{3}\pi r^3$$
$$= 3\rho V \text{ per unit volume per unit time} \quad .. \quad (2)$$

Matter receding from O with a velocity exceeding the velocity of light c would be unobservable to O. Hence O would place the boundary of his theoretically observable universe at the distance R, where the speed of recession is c, i.e.:

$$R = c/V \quad .. \quad .. \quad (3)$$

The mass M inside this distance is

$$M = \tfrac{4}{3}\pi\rho R^3 = \tfrac{4}{3}\pi\rho(c/V)^3 \quad .. \quad (4)$$

Any fundamental observer must therefore describe the universe as having radius R and mass M. Despite the continued creation of matter, it is to be noted that the mass of the universe is conserved.

The acceleration of a particle with velocity $V\mathbf{r}$ is $V^2\mathbf{r}$. The observer O, using Newtonian gravitation for a spherically symmetrical distribution of density ρ, assigns an acceleration due to gravity $-\tfrac{4}{3}\pi\gamma\rho\mathbf{r}$, where γ is the gravitation constant. Therefore he must postulate a repulsive force per unit mass of amount $\tfrac{1}{3}c^2\lambda\mathbf{r}$ in the notation of section 4, where

$$\lambda = 3(V/c)^2 + 4\pi\gamma\rho/c^2 \quad .. \quad (5)$$

Thus the model requires a non-zero cosmical constant, at any rate for this type of mechanical description. So this description does not yield a relation between ρ and V alone.

We then notice that O would evaluate the Newtonian velocity of escape from the material within distance r as $\{2(\tfrac{4}{3}\pi\gamma\rho r^3)/r\}^{\frac{1}{2}}$. Since the material at this distance has speed Vr, he would say that the material at all distances has the velocity of escape if

$$\rho = 3V^2/8\pi\gamma \quad .. \quad .. \quad (6)$$

TABLE I

Constants of the model universe

Recession constant	V	$1{\cdot}8 \times 10^{-17}\ \text{sec}^{-1}$	$V\mathcal{T} = bN^{-1}$
	b	$0{\cdot}38$	
Density	$\rho = \dfrac{3}{8\pi}\dfrac{V^2}{\gamma}$	$5{\cdot}8 \times 10^{-28}\ \text{g cm}^{-3}$	$\rho\dfrac{\mathcal{L}^3}{\mathcal{M}} = \dfrac{3b^2}{8\pi}N^{-1}$
Creation rate	$\mu = \dfrac{9}{8\pi}\dfrac{V^3}{\gamma}$	$3{\cdot}1 \times 10^{-44}\ \text{g cm}^{-3}\ \text{sec}^{-1}$	$\mu\dfrac{\mathcal{L}^3\mathcal{T}}{\mathcal{M}} = \dfrac{9b^3}{8\pi}N^{-2}$
Cosmical constant	$\lambda = \dfrac{9}{2}\dfrac{V^2}{c^2}$	$1{\cdot}6 \times 10^{-54}\ \text{cm}^{-2}$	$\lambda\mathcal{L}^2 = \dfrac{9}{2}b^2N^{-2}$
Radius of observable universe	$R = \dfrac{c}{V}$	$1{\cdot}7 \times 10^{27}\ \text{cm}$	$\dfrac{R}{\mathcal{L}} = \dfrac{1}{b}N$
Mass of observable universe	$M = \dfrac{1}{2}\dfrac{c^3}{\gamma V}$	$1{\cdot}1 \times 10^{55}\ \text{g}$	$\dfrac{M}{\mathcal{M}} = \dfrac{1}{2b}N^2$

$\mathcal{L}$, $\mathcal{M}$, N, and $\mathcal{T}$ refer to Dirac units; see table II.

Relation (6) is a consequence of Hoyle's theory (section 12), but, as he remarks, we might expect something like it on general grounds. For, were the velocity less than the velocity of escape, then on ordinary gravitational ideas we should not expect the recession to be maintained. On the other hand, were the velocity much greater, we should not expect the formation of condensations (galaxies) (section 13). Also the numerical value of ρ given by (6) is plausible on observational grounds [16]. So, although (6) is not a necessary consequence of the model, we shall adopt it here.

Numerical results are given in table I. Column 1 gives also the expressions for the other constants in terms of V, obtained by using (6) in (2), (4), and (5).

11. *Discussion.* The only empirical value is that of V from (1). We have already quoted Hoyle as to the plausibility of the value of ρ. As regards the value of μ, we may remark that it corresponds to the creation of about 500 hydrogen atoms per cubic kilometre per year, showing how impossible it would be to observe directly.

There is one interesting possibility of gaining general confirmation of the values found. Dirac has proposed as a principle of cosmology: 'Any two very large dimensionless numbers occurring in Nature are connected by a simple mathematical relation in which the coefficients are of order of magnitude unity.' He infers that, if $\mathcal{N}$ is any such number, then any other is to a first approximation a small integral power of $\mathcal{N}$ multiplied by a factor of order unity. He applies the principle to a different model, but we can see what it gives in our case.

Following Dirac, the relevant numbers are obtained by expressing the characteristics of the universe in physical units: those he selects are shown in table II. The number $\mathcal{N}$ which he uses for a standard of comparison is the ratio of the electrical to the gravitational force between a proton and an electron.

It has several times been remarked that the recession constant V multiplied by the time-unit used by Dirac gives a dimensionless number of the order $\mathcal{N}^{-1}$. If we write this product as $b\mathcal{N}^{-1}$, then the remaining constants of our model yield the numbers in table I, column 3. The coefficients are of what Dirac regards as 'order of magnitude unity' in the context. So we can claim that the model conforms to Dirac's principle. Therefore, in so far as we accept the principle, we can take it as favourable to the steady-state hypothesis.[1]

This conformity to the principle also indicates that the characteristics of the universe are closely related to fundamental atomic constants. This is what we should expect if the behaviour of the universe is determined by the creation process, i.e. an atomic process [17].

Finally, it is important to note that though the model gives an infinitely old universe in a steady state, it automatically escapes the conclusion that such a universe must have attained thermodynamic equilibrium. The maintenance of the one-way process of creation ensures, in fact, that it is not in thermodynamic equilibrium. This is in qualitative agreement with observation.

To sum up, we have a model that, as well as can be judged, reproduces the existing general state of the universe, possesses characteristics conforming to Dirac's requirements, and, having maintained the same state for an infinite time, should present no difficulty of inadequate time for the evolution of its contents.

12. *Field theory.* This model gives only a preliminary survey of what a coherent theory incorporating the new concepts is expected to produce. Hoyle [12, 15] has given tentative formulations of such a

TABLE II

'Dirac units'

Time	$\mathcal{T}$	$\frac{e^2}{mc^3}$	$\gamma\frac{\mathcal{M}\mathcal{N}}{c^3}$	$0{\cdot}94 \times 10^{-23}$ sec
Distance	$\mathcal{L}$	$\frac{e^2}{mc^2}$	$\gamma\frac{\mathcal{M}\mathcal{N}}{c^2}$	$2{\cdot}8 \times 10^{-13}$ cm
Mass	$\mathcal{M}$	$\mathcal{M}$	$\mathcal{M}$	$1{\cdot}7 \times 10^{-24}$ g
Dimensionless number ..	$\mathcal{N}$	$\frac{e^2}{m\mathcal{M}\gamma}$	$\mathcal{N}$	$2{\cdot}3 \times 10^{39}$

e, m = electronic charge, mass; $\mathcal{M}$ = proton mass.

[1] Admittedly, the characteristics of the model are so related by (2)–(6) that the satisfaction of Dirac's principle by some of them ensures it for the others. But this is partly the point at issue: we have not to introduce characteristics violating the principle.

theory by investigating field equations that resemble Einstein's as closely as possible without implying the conservation of matter. The model he derives has almost exactly the same characteristics as that described above. The only exception is that he does not require the cosmical constant λ; this is satisfactory, since we had to introduce λ only in order to give a purely Newtonian description of the phenomena.

Further, the treatments both of Hoyle and of Bondi and Gold yield for the metric of space-time, in the sense of representing light-tracks as null-geodesics, the metric of de Sitter's universe. But, since Einstein's equations are not assumed, there is no question of this being an empty universe. In fact, taking the density in accordance with their postulates, Bondi and Gold calculate with the aid of this metric the relative number of galaxies down to any given apparent magnitude. Comparison with observational surveys gives better agreement than that achieved by dative models with more disposable parameters.

EVOLUTION OF GALAXIES

13. *Galaxies.* We proceed to considerations beyond those associated with an entirely smoothed-out universe. All cosmological theories agree in regarding a galaxy as the primary type of concentration of matter. According to the new ideas, the number n of galaxies per unit volume of space is statistically constant. Newly created matter will in general tend to fall into the nearest galaxy. Thus any existing galaxy is continually growing by accretion. But the continual creation throughout space means that there is always an intergalactic distribution of matter. Now this intergalactic matter must exhibit fluctuations of density owing to the randomness of the creation process, irregularities in the gravitational field, etc. A sufficiently large fluctuation above the mean density in its neighbourhood must itself grow by accretion. Thus the mutual recession of existing galaxies is compensated by the birth of new ones, so maintaining the constancy of n. Any sufficiently large region of space must contain galaxies of all ages.

Consider again the model in section 10. Since the speed at distance r from O is Vr, the nebulae at distance r at time $t+T$ were at distance re^{-VT} at time t. Now let $n.f(a)$ be the number of galaxies per unit volume of age exceeding a. At time t the number of these within the sphere of radius r is $\frac{4}{3}\pi r^3 n.f(a)$. At time $t+T$ the number in the same sphere consists of those which at time t were of ages exceeding $a-T$ and were within the sphere of radius re^{-VT}, that is $\frac{4}{3}\pi r^3 ne^{-3VT}f(a-T)$.

But this must be the same as at t: hence

$$f(a) = e^{-3VT}f(a-T),$$

giving
$$f(a) = e^{-3Va} \quad \ldots \quad (7)$$
since, by definition, $f(0)=1$. Therefore the number of galaxies per unit volume of age a or more is ne^{-3Va}; the number of age between a and $a+da$ is $3n.Ve^{-3Va}da$; and the mean age is:

$$3V\int_0^\infty ae^{-3Va}da = 1/3V \doteqdot 6 \times 10^8 \text{ years.}$$

But there is the further question of how old a galaxy must be in order to be observed as a galaxy. We must conclude that the mean age of recognizable galaxies is appreciably greater than this estimate.[1] This is then a plausible result.

The present theory predicts a mixture of galaxies of various ages at all distances from an observer. On the other hand, the dative theories predict that the galaxies all have the same age t at the cosmic epoch t, being actually seen at an earlier age the farther they are from the observer. The difference between these predictions ought to make possible a discrimination between the theories when observational criteria of age have been determined.

A few further numerical considerations are interesting. We first recall the values:

Mean separation [18] of neighbouring galaxies ..	$2l = 1{\cdot}2 \times 10^{24}$ cm
Mass of Galaxy	$M_0 = 5 \times 10^{44}$ g
Age of Galaxy	$T_0 = 5 \times 10^9$ years.

The values of l, M_0 are those accepted from observational data; the value of T_0 has been quoted in section 6.

Using the values of ρ, μ in table I we find for the average mass M_1 within any sphere of radius l and the total mass M_2 created within the same sphere during time T_0:

$$M_1 = 5{\cdot}2 \times 10^{44}\text{ g.} \quad M_2 = 4{\cdot}4 \times 10^{45}\text{ g.}$$

Also the time T_1 of free fall from distance l, to a distance small compared with l, under the gravitational attraction of mass M_0 is:

$$T_1 = \tfrac{1}{2}\pi(l^3/2\gamma M_0)^{\frac{1}{2}} \doteqdot 2{\cdot}8 \times 10^9 \text{ years.} \quad (8)$$

[1] If $2l$ is the mean distance between a galaxy and its nearest neighbour, then no new galaxy can be born, and remain distinct, much nearer to O's galaxy than distance l. Such a galaxy would in general recede to distance R in time $(1/V)\log_e(R/l) \doteqdot 1{\cdot}4 \times 10^{10}$ years, using the observed value $l \doteqdot 6 \times 10^{23}$ cm and V,R from table I. Consequently O can expect actually to see no galaxy older than this, unless it be his own or gravitationally bound to his own. This argument is due to Hoyle (*l.c.*). But (7) gives only one galaxy in over 1000 million older than this, so the argument has no effect on our conclusions.

Since M_0, M_1 are of the same order, we can conclude in a general way that a sphere of radius l about the Galaxy is not unreasonable as a 'sphere of influence.' This is confirmed by T_0, T_1 being of the same order, so that in fact the Galaxy during its lifetime could have captured material from within such a sphere. We have then to remember, of course, that the value of M_0 to be used in (8) would have been smaller in the past. So a considerable amount of the matter represented by M_2 would not have had time to fall into the Galaxy and some also would have receded from its sphere of influence. It is thus satisfactory to find that M_2 is considerably greater than M_0.

These elementary comparisons show that the times and masses involved are consistent with the idea of the Galaxy having grown by accretion.

Lastly, we may remark that the Galaxy is usually held to be something of a giant among galaxies in general, whose mean mass has been variously estimated at 1/10 to 1/100 of M_0. The figures already given show also that it is fairly old compared with the average. This association of mass and age gives qualitative support to the idea of growth by accretion.

If these ideas prove successful, the important quantities of which they should provide theoretical values include the mass of a galaxy of given age, the mean separation of galaxies, and the ratio of galactic to intergalactic matter.

14. *Clusters.* The majority of galaxies appear to be isolated individuals, but they may also occur in associations ranging from groups of several members (our Galaxy belonging to the 'local group' of about a dozen members) to clusters of several hundreds.

Bondi and Gold claim for the steady-state theory that it accounts naturally for this clustering tendency. Their explanation of the formation of clusters is basically the same as that we have given for the formation of the galaxies themselves. Just as a random distribution of atoms must tend to form condensations owing to the gravitational instability we have described, so a random distribution of galaxies must tend to form condensations, i.e. clusters, by the same process.

On these authors' view the operative time required for clustering to get under way is that for two galaxies to fall together from a separation of the order of $2l$. If both masses are about that of the Galaxy, this is about 6×10^9 years; if both are about one-tenth of that mass, it is about $1 \cdot 7 \times 10^{10}$ years. After such an interval, further galaxies may be captured at an increasing rate. Thus the times involved are just permissible on the views here stated concerning the ages of the galaxies themselves. In further support, Hoyle argues that our Galaxy, being a moderately old one, would be expected to be involved in a moderate degree of clustering, which is indeed the case.

REVIEW

15. In its present state, cosmological theory probably impresses the general theoretical physicist as a highly unsatisfactory subject. Though general relativity provides an elegant theory of the expanding universe, yet when cosmologists attempt to square its prediction with the observations, they resort either to unverified physical hypotheses (about spectral-shifts), or to mathematical devices such as the use of two time-scales and the treatment of universal 'constants' as being secularly variable. The creation hypothesis may appear to be just one more makeshift. In spite of the obvious need for further work, it can, however, be claimed to be of a different status.

REFERENCES

[1] BONDI, H., and GOLD, T. *Mon. Not. R. Astr. Soc.*, **108**, 252, 1948.

[2] ROBERTSON, H. P. *Rev. Mod. Phys.*, **5**, 62, 1933.
TOLMAN, R. C. *Relativity, Thermodynamics, and Cosmology*, Section x (Oxford, 1934).
HECKMANN, O. *Theorien der Kosmologie* (Berlin, 1942).
BONDI, H. *Mon. Not. R. Astr. Soc.*, **108**, 104, 1948.

[3] MILNE, E. A. *Nature*, **130**, 9, 1932.

[4] *Idem. Relativity, Gravitation, and World-structure* (Oxford, 1935); *Kinematic Relativity* (Oxford, 1948).

[5] *Idem. Quart. J. Math.* (Oxford Series), **5**, 64, 1934.

[6] MCCREA, W. H., and MILNE, E. A. *Ibid.*, **5**, 73, 1934.

[7] *Idem. Ibid.*, **5**, 73, 1934, equation (21).

[8] HUBBLE, E. B. *The Realm of the Nebulae* (Oxford, 1936); *The Observational Approach to Cosmology* (Oxford, 1937).
HECKMANN, O. *Theorien der Kosmologie*, Ch. 17 (Berlin, 1942).

[9] MILNE, E. A. *Kinematic Relativity*, § 137 (Oxford, 1948).

[10] *Idem. Ibid.*, §§ 253, 247–8.

[11] DIRAC, P. A. M. *Proc. Roy. Soc.*, **A**, **165**, 199, 1938.

[12] HOYLE, F. *Mon. Not. R. Astr. Soc.*, **109**, 365, 1949.

[13] JEANS, J. H. *Astronomy and Cosmogony*, 352 (Cambridge, 1928)

[14] DIRAC, P. A. M. *Nature*, **139**, 323, 1937.

[15] HOYLE, F. *Mon. Not. R. Astr. Soc.*, **108**, 372, 1948; *Nature*, **163**, 196, 1949; *The Listener*, **41**, 567, 1949.

[16] *Idem. Nature, loc. cit.*

[17] *Idem. Mon. Not. R. Astr. Soc.*, **108**, 381–2, 1948.

[18] WALDMEIER, M. *Einführung in die Astrophysik*, 322 (Basle, 1948).

[19] JORDAN, P. *Nature*, **164**, 637, 1949.

Life between tidemarks in North America

T. A. and ANNE STEPHENSON

Professor and Mrs Stephenson have been working for many years on a survey of intertidal ecology, and their studies have taken them not only round the shores of Britain but to Australia, South Africa, Mauritius, and North America. In the present article they describe some of the observations made on two recent expeditions to North America, in which they covered about 20,000 miles. Plates 2, 3, and 4 are from the authors' original paintings.

The rate of development of the different branches of biology is curiously uneven, and this is exemplified by our present knowledge of life in the sea, as reflected in the current textbooks or monographs on the subject. Marine life may be studied in two ways, (*a*) by working along the narrow strip (tidal belt, intertidal zone) exposed along the coasts of the continents at low water, and (*b*) by investigation of the off-shore waters, and of the sea floor, from vessels. The tidal belt is naturally much more accessible than the oceans, and has the advantage that one can walk over it and see it as a whole; moreover, in connection with the rise and fall of the tide which alternately covers and uncovers it, it presents a peculiarly changeable and fascinating environment for life. The ocean floor can never be examined in nearly the same detail, except in so far as small areas can be seen by diving, a method which has marked restrictions. It is therefore rather unexpected to find that, in a broad sense, knowledge of the oceans has outstripped that of the tidal belt.

By far the most comprehensive general account of the sea as an environment for organisms is *The Oceans*, by Sverdrup, Johnson, and Fleming, a book which appeared in 1942. It surveys our knowledge of the seas very fully, and deals also with the plants and animals which inhabit them. It tells us relatively little, however, about life between tidemarks. Similarly, the most comprehensive book which has yet been written about animal life in the sea (*Tiergeographie des Meeres*, by Sven Ekman, 1935) deals with the sea and its floor as a whole, but, while part of it is relevant to the tidal region, it does not refer specifically to this belt. There is no general work devoted to the biology of marine plants on a world scale, though there are sections on their distribution in books mainly devoted to algal morphology (e.g. *The Structure and Reproduction of the Algae*, by Fritsch, 1945). If we turn to the literature of the intertidal zone itself, we find that, while it is vast, the bulk of it covers detail rather than gives broad outlines. Thus, while we can point to numerous works which deal with the systematics of shore-living species, the biology of particular plants and animals, or the ecology of small areas (especially very small ones), we cannot find many examples of broad-scale ecology, although a notable exception exists in the numerous papers by Fischer-Piette on the coasts of the English Channel. There have also been many books on seashore life, yet none of them attempts to provide a world-wide picture such as is supplied for offshore waters by the books mentioned above. The nearest approach to such a thing is *Between Pacific Tides*, an account of the Pacific coast of North America by Ricketts and Calvin, first published in 1939.

It has been our own persistent aim to do what we can towards supplying a broader picture of intertidal ecology than has yet appeared, and we have been working towards this end over the past thirty years in Britain, Australia, South Africa, Mauritius, and North America. During the ten years which we spent in South Africa (1931–40) we organized a coastal survey in which we were assisted by a dozen younger workers. This provided the first general ecological review of a coastline of nearly 2000 miles, and was published as a series of over fifty papers, the references to which will be found in the final item, *The Constitution of the Intertidal Fauna and Flora of South Africa*, Part III, in the *Annals of the Natal Museum*, vol. XI, 1948. During this survey the coast between the mouth of the Orange River in the west, and the frontier of Portuguese East Africa in the east, was visited at about 100 points, and throughout the work the seaweeds and animals were considered in their relation to one another. From this project arose two others, one or both of which we hope to develop in the coming years. The first is to survey the British coast in the same way as we did the

South African, because in spite of all that has been published the material still does not exist for a broad ecological account of it. The second is to write a book on plant and animal life between tidemarks in the world as a whole. It was in connection with this second project that the journeys to North America described in this article were made. It is obvious that any book which deals with an area as vast as the whole world can do so only on the basis of a series of samples. We had seen, before 1947, a number of such samples, but we felt that there were certain others which we ought to see at first hand before embarking on our book. It so happened that they could mostly be found on the very varied coasts of North America.

On the first expedition we arrived at New York on 1st January, 1947, and left again on 25th January, 1948. During the intervening thirteen months we started work on the Atlantic coast in Florida, where we bought a car in which the rest of our journey could be made. The work required a rather massive amount of equipment, and by far the most economical method of transporting this and ourselves was to drive. From Florida we went first to Charleston in South Carolina, thence to Beaufort in North Carolina. After this we crossed the continent, with a pause at Washington, to Nanaimo in British Columbia, and thence moved south to California, ending at San Diego near the Mexican border. We covered altogether some 15,000 miles, and our schedule allowed us to stop for about two months at each of the main centres from which we wished to work. Though a period of two months is not long, a surprising amount can be seen on the shore during such a time by two people working together who have been doing similar work for many years previously. The expedition was made possible by grants from several institutions and by the kindness of various American marine stations in providing us with facilities. It is a pleasure to acknowledge our indebtedness to all who helped us; we have done so in more detail elsewhere.

The North American continent offers an immense variety of seashores, from the tropical coasts of Florida and the Panama region, through warm-temperate and cold-temperate variations to the more or less icebound northern regions. A great deal has been written about the biology of American shores, but there are relatively few general ecological accounts. We chose our localities as far as possible in regions which not only offered what we ourselves wished to see, but of which the general ecology had not been described. Our first objective was to see something of the Florida Keys, that strange chain of low islands strung out between Miami and Key West. We did not specially need to see a typical tropical shore, as we had seen a variety of these in Australia and the Indian Ocean, but Florida provides a very exceptional tropical area in which, in a very shallow, sediment-laden sea, a strangely limited intertidal population inhabits reefs of clinker-like coral rock (figure 2). It was the abnormality of this area which attracted us, as we hoped that by comparing it with more ordinary tropical regions some of the principles which control its peculiarities would be revealed. After leaving the Keys we went on to the northern part of Florida and North and South Carolina, where (between Cape Canaveral and Cape Hatteras) another unusual stretch of coast is to be found. In this case the marine climate is warm-temperate, but the inhabitants of intertidal rock (on which our attention is concentrated) are subjected to adverse conditions of a different type from those of southern Florida. The coastline is predominantly sandy, and there are few outcrops between tidemarks of any material harder than peat; their absence is partly made up for by the existence of rough, rocky breakwaters, some of them very large, which are very like natural reefs. In this area one can study not only the reaction of warm-temperate North Atlantic species to the presence of small rocky areas lost in seas of sand, but also (especially in North Carolina) the interesting overlap between northern cold-water species and southern warm-water ones. Another peculiarity of the northern part of this area is that those very characteristic shore animals, the limpets, which are of almost world-wide distribution, do not seem to be present at all on open rock-surfaces on the Carolina coasts which we visited.

On the Pacific coast our three centres offered entirely different sets of conditions. Here we were dealing everywhere with rich and abundant marine populations not subjected to adverse conditions, the marine climate being cold-temperate in the north and warm-temperate in the extreme south. At our first station, Nanaimo, in a region of quiet creeks showing reduced wave-action, there flourishes an astonishing marine population in water the salinity of which, while a good deal below that of normal sea-water, is not low enough to create estuarine conditions. It is a peculiarity of the fauna and flora here that many of the common species are very large and striking

FIGURE 1 – *A view of the shore at the entry to Mason's Cove, one of the narrow marine inlets communicating with St. Margaret Bay, on the Atlantic coast of Nova Scotia. The inlet is remote from the open sea, and in hard winters may freeze over its whole surface for some time. This photograph, taken in summer, shows a variety of intertidal zonation which is characteristic of such inlets in Nova Scotia. Below the trees, which approach very near to high-water level, the granite boulders which line the shore show a whitish band. This represents the region in which the natural pale grey or whitish colour of the granite is most clearly visible; above this level it is commonly obscured by land-lichens and other vegetation, below it by intertidal agencies. Below this pale band is a black zone, very sharply marked and showing a striped appearance in places. This zone is due to a film of blue-green algae (often blackish in colour) and intertidal lichens, and is submerged by the sea only at the higher spring tides. Below this again lies a belt in which the granite is discoloured to a buff or pale-brown tint. There follows a wider zone carpeted by fairly large brown seaweeds* (Fucus *and* Ascophyllum), *and this seaweed zone shows a gradual change in colour from a yellowish brown above to a darker shade below, the colour change corresponding to a change in the nature of the population. The photograph was taken at low water of a moderate tide; but sometimes the tide falls lower than this and exposes a muddy zone below the belt of seaweed. The latter belt corresponds approximately to the midlittoral zone mentioned in the text.*

FIGURE 2 – *A dead coral reef: Plantation Key, Florida. The coral rock is colonized by small organisms which occupy zones in each of which the colour of the rock is affected in a different way.*

FIGURE 3 *A group of large starfish* (Pisaster ochraceus) *in British Columbia.*

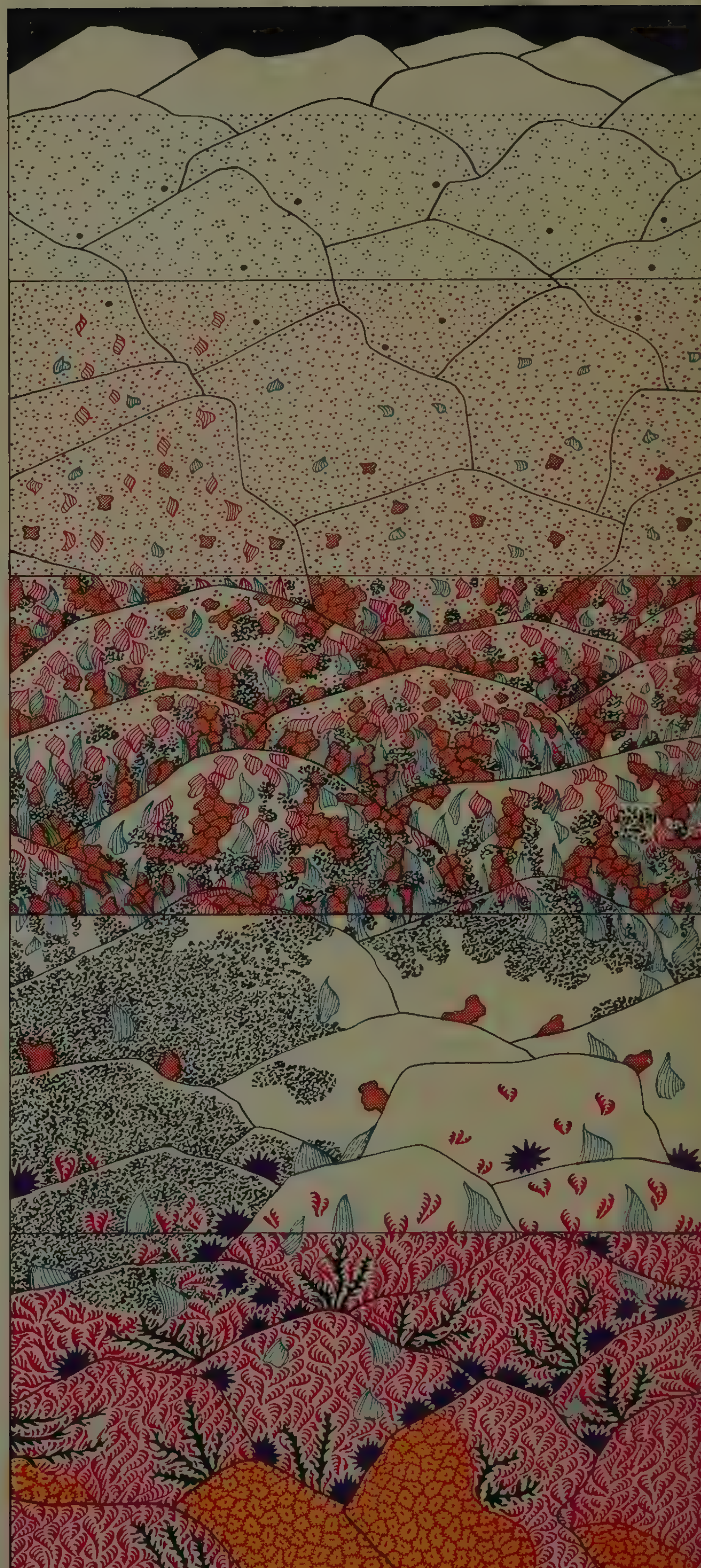


FIGURE 4 – *Diagrammatic representation of the arrangement in zones of some of the commonest plants and animals on rocky breakwaters near Beaufort, North Carolina. The lowest zone represents the infralittoral fringe, the highest the supralittoral fringe. Between these lies the midlittoral zone with three subdivisions.*

—plumose anemones a foot high, acorn-barnacles six inches across the base, seaweeds forty feet long, and above all bright violet starfish eighteen inches across and weighing over two pounds (figure 3). In this region we studied, among other features, a small island which has a sunny, gradual slope along its southern shore and a shaded cliff along its northern one; this provided a diagrammatic example of the differences which these two combinations of conditions produce in the distribution of the common intertidal species. At our next centre, the Monterey Peninsula and Point Lobos in California, there is a very strong contrast to Nanaimo, for here, while the population is again rich and varied and the sea of normal salinity, the coast is open to the Pacific swell, so that there are many wave-beaten promontories subject to seas of terrific power. So rugged is the coast, however, that despite the strong wave-action one can find, within a short distance of each other, areas showing all degrees of exposure to and shelter from the waves, so that the very sensitive reactions of the intertidal plants and animals to these variations can be studied. At our final station, La Jolla in southern California, is to be seen a rocky coast subject to wave-action stronger than that at Nanaimo, yet more moderate than that near Pacific Grove. Here, however, the population is warm-temperate, and the rock, while in the main abnormally soft, shows many local variations in hardness, with the result that one can study to advantage the very marked effects on the plants and animals of such variations.

During our second visit to America (June to September 1948) we studied rocky areas in Nova Scotia and Prince Edward Island, travelling altogether some 4000 miles. Here we were able to compare a typical open north-Atlantic coast, such as is found at Peggy's Cove near Halifax, with other coasts which, though occupying the same geographical region, show differences from the normal pattern owing to their special circumstances. Thus while the open coast near Peggy's Cove is little if at all affected by ice in the winter, some of the other coasts studied are scoured by it very markedly. Along the northern coast of Prince Edward Island, for instance, the ice may form for a mile out from the shore and pile up in irregular masses on the intertidal rocks, almost to the height of the cliffs. Factors other than ice are also involved.

One of the striking features of most rocky shores is the way in which the plants and animals populating them are arranged in horizontal bands, one above the other and often overlapping. These bands or zones vary in distinctness. Sometimes they are rather vaguely marked, sometimes their edges are so sharp that they might have been drawn with a ruler (as in the 'black zone' shown in figure 1). The existence of these zones and the possible reasons for it have been discussed extensively in the literature of the subject, but the problem is by no means fully solved. It is one to which we have paid particular attention. During the South African survey mentioned above we developed the idea that the zonation which is there apparent on the shore represents one of the possible variants of a fundamental plan which is of more or less universal occurrence. We tested this idea later in Britain, Mauritius, and East Africa, and more extensively during 1947–8 in North America. The information collected has yet to be developed before the theory can be applied in detail, but our general impression is that it has stood the test well. Stated in its simplest terms, the plan of zonation found on various coasts of the world tends to show (*a*) an arid zone transitional from land to sea, not covered by the sea at all high waters, the *Littorina zone* or *supralittoral fringe*; (*b*) a middle belt more regularly covered and uncovered by the sea, the *Balanoid* or *midlittoral zone*; and (*c*) a lower zone uncovered only at the lowest tides, the *infralittoral fringe*. This is, however, an extreme simplification, and each of the main zones (especially the midlittoral zone) shows subdivisions on many coasts, and there are complications of all descriptions. An example of zonation as developed on breakwaters near Beaufort in North Carolina is shown in figure 4, and in figure 1 is reproduced a photograph illustrating the zonation in a protected inlet in Nova Scotia.

While our American expeditions consisted primarily of field work and the collection of information, this was only the first step towards the object in view, which is to elucidate, by a study of the ways in which populations vary under all sorts of different conditions, the fundamental principles at work behind the surface appearances. These principles cannot, however, be formulated until a much more searching examination of the facts has been made than has yet been possible. There is also a large amount of information in the literature which will need to be tabulated and co-ordinated before the book towards which we are working can be written, but the task—almost impossible for anyone who has not seen a great variety of sea shores at first hand—will be much facilitated by this recent addition to our own field experience.

The International Union of Pure and Applied Chemistry

R. DELABY

'Chemistry,' according to Duclaux, 'is the basis of everything, and nothing escapes it.' Time has emphasized the truth of this sweeping generalization; today chemistry plays a dominant role in every civilized country. The need for international co-ordination in chemistry was first recognized by the formation of the International Association of Chemical Societies, founded before 1914. This has been succeeded by the present International Union of Pure and Applied Chemistry, of which Professor Delaby is Secretary-General.

Among the ten unions which at present form the International Council of Scientific Unions (I.C.S.U.), the International Union of Pure and Applied Chemistry, founded in 1919, has given ceaseless proof of its achievements. To try to give here even a summary account of its achievements would be impossible. This article recalls its origins, describes its present structure, and demonstrates its active participation in scientific progress.

Scientific societies contribute to progress by facilitating the exchange of information between scientists carrying out the same kind of research.[1] A second stage consists of bringing together groups in the same branch of science, founded in the same country, into a federal organism. Finally a union supplies, on an international plane, the indispensable ties between societies through the mediation of these national organisms.

This is the idea of the International Union of Pure and Applied Chemistry, which is: 'to organize permanent co-operation between the chemical associations of the membership-countries, to co-ordinate their scientific and technical resources, and to contribute to the advance of chemistry in the whole range of its domain, especially through the organization of conferences, congresses, and symposia.' This rubric, from Article 1 of its statutes, has not been appreciably changed over the last twenty years.

ORIGINS

The armistice at the end of the first world war had not yet been signed when the delegates of the scientific academies of the allied nations met in London in October 1918, and then in Paris the following month, with the intention of forming an International Council of Research. This body set itself in particular the task of co-ordinating the activities of the different branches of science and their practical application, of establishing contacts with the governments of the member-countries, and of facilitating the formation of international groups capable of contributing to the progress of science.

From the latter point of view, chemists of many countries had been concerned with their mutual relationships well before 1914: there was already in existence an International Association of Chemical Societies, including about fifteen societies, presided over by the famous French organic chemist Albin Haller and subsidized through the philanthropic generosity of Ernest Solvay. That was only a beginning. In November 1918 the Society of Chemical Industry received Paul Kestner, president and founder of the *Société de Chimie Industrielle*, and on this occasion negotiations were begun on exactly the same subject as that proposed by the International Council of Research. They ended in a conference in Paris in April 1919, bringing together the chief scientific and industrial groups of the allied countries: Belgium, U.S.A., France, Great Britain, and Italy. The main decision taken was that the chemical associations in each country should be invited either to create a national council made up of their delegates, or to form themselves into a federation; these national organizations were then to be grouped together into a confederation, which would afterwards become international by inviting the neutral countries to membership. In this way each country would send to the conference delegates representing the whole of its scientific and industrial associations, and no longer the delegates of a single society as in the former International Association of Chemical Societies, the dissolution of which was being considered at that time. A provisional council was nominated, and its president, Charles Moureu, *Membre de*

[1] *Cf.* ENDEAVOUR, *The Role of Scientific Societies*, 1947, **6**, 49.

l'Institut de France, was specially charged with the task of establishing contact with the International Council of Research, the project for which was under the aegis of the academies.

The Interallied Confederation of Chemistry was formed three months later in London; it adopted statutes, elected a board, established its provisional headquarters in Paris, and gave the Italian delegation the task of preparing for the next meeting in Rome in June 1920.

A delegation appeared immediately before the Chemistry Commission of the International Council of Research, which was holding its meetings in Brussels (22nd July, 1919); the delegation requested the integration of the new confederation, which was to have autonomous power 'within the framework of the organizations foreseen by the Scientific Academies, as the chemistry section of the International Council of Research.' In the course of this meeting, and following upon a favourable referendum of the members of its council, the International Association of Chemical Societies was declared dissolved. It was replaced by the Interallied Confederation, which was admitted into the International Council of Research, with the adaptation of its statutes to the general principles laid down by the Council; its title henceforth was to be the 'International Union of Pure and Applied Chemistry.'[1] In recognition of services previously rendered by the International Association of Chemical Societies, the presidentship was offered to Albin Haller, who, however, declined this unanimous offer from his colleagues, and Charles Moureu was elected the first president.

CONSTITUTION AND PROCEDURE

The Union's activities are carried out by a council through sections, such as inorganic chemistry, organic chemistry, biological chemistry, physical chemistry, analytical chemistry, applied chemistry, and through commissions, most of which are attached to these sections. Their meetings, attended by the whole or part of the Union and designed to take place at least every two years, are known as conferences.

The Council is composed of delegates, nominated by the subscribing organizations; the number of delegates depends on the category to which the corresponding country belongs, the three categories themselves being fixed according to the activities in the realm of chemical science which that country develops. The Council is very similar to the Houses of Representatives existing in democratic countries where they possess legislative powers. It deals with scientific as well as administrative and financial questions. At the present time 31 countries possess an organization attached to the Union.

Executive powers were vested in a board elected from the Council and composed of, at the most, 17 individuals: a president, six vice-presidents, six elected members, a general secretary, a treasurer, and the two past-presidents.

Experience having proved the difficulty of bringing together all the members of the board between conferences, the powers of the board have been delegated to an executive committee formed by the president, a vice-president, one elected member, the general secretary, and the treasurer.

The work is shared between permanent and temporary commissions, charged either with the administration of the various organizations of the Union, such as the permanent commission for finance, or with the study of given problems. The scientific and technical commissions are composed of specialists. They may include qualified members elected by the commissions, and delegate members of interested bodies such as offices of weights and measures and research institutes. They can add to their numbers, in an advisory capacity, national representatives and observers, invited by their presidents.

Provision is also made for affiliated committees which, for example, set out to unify methods of analysis or of control in a specialized discipline; the extremely active commission for the study of fats is of this kind, and it would be desirable to include in the Union other similar commissions.

Since the war, the I.C.S.U. has created mixed commissions from among the international unions, attached to a central union which is the one most clearly interested. Thus the Union of Chemistry is the central union of the commission on standards, units, and constants of radioactivity, which includes the delegates of the International Union of Pure and Applied Physics.

These commissions are to the Union what the circulation is to a man; they supply the organism continuously with new blood. At the fourteenth conference President Bogert appropriately recalled the fact that the president of a commission should be abreast of research carried out in his branch by other individuals and institutions

[1] From 1930 to 1949 it was called simply '*Union Internationale de Chimie*'; at the 15th Conference (Amsterdam, 5–10th September, 1949) it was thought preferable to state in the title that the Union interested itself in both the theoretical aspect and the applications of chemistry.

recognized generally as outstanding; for thus he can make an infallible selection from among his colleagues. 'He is like a generalissimo in a high observation post, with the field for his operations spread out before him. His office should be the world's authoritative information centre for the subject covered.'

CONFERENCES AND SYMPOSIA

Since its formation the Union has held fifteen conferences. At first these meetings were annual, so as fully to ensure an intellectual intercourse between chemists throughout the world and to take many desirable decisions; then the rhythm became two-yearly after 1928, apart from a four-year interruption between 1930 and 1934 and a much longer break (1938–47) due to the second world war; but in 1946 contact was reopened in London.

In principle, each conference first hears a presidential report on the general state of the Union and a report from the treasurer on the financial situation. Administrative questions are next discussed. After these, it is the scientific subjects treated by various commissions which particularly hold the interest of the conference; the presidents report upon the work which has been carried out—work not seldom leading to international conventions, or standardizations, or progress of other kinds. It would be banal to recall the universality of the world of chemistry, and Duclaux was prophetic when, more than half a century ago, he said: 'Chemistry is the basis of everything, and nothing escapes it.'

Proceedings were published after each conference, and now form an impressive collection of 2142 quarto pages. It should be added that there are certain reports which are too highly specialized or too voluminous to be included in proceedings; some of them have been circulated by publishing houses, e.g. 'Tables of Reagents for Mineral Analysis,' available in three languages (409 pp.), and 'Recommended Reagents' (288 pp.), which constitute two fundamental reports of the commission of new analytical reactions and reagents.

In addition to the conferences and to the congresses (the history of which will briefly be sketched), the Union has recently made arrangements for a number of more restricted reunions called symposia; qualified specialists will here speak on subjects which are still in process of development, or will treat more particular topics. Two symposia on macromolecular chemistry (Liège, 1948; Amsterdam, 1949) presided over by Professor H. Mark, have already proved a great success.

CONGRESSES OF PURE AND APPLIED CHEMISTRY

Before the formation of the Union, international congresses of applied chemistry were held periodically and assumed a steadily increasing importance. The initiative in this was taken by the Belgian Association of Sugar Refining Chemists, soon seconded by the analogous association in France and her colonies. The first congress was held at Brussels in 1894, and the second in Paris in 1896, when 1500 members presented 194 reports, a remarkable achievement for the time. Others followed: Vienna (1898), Paris again (1900), Berlin (1903), Rome (1906), and London (1909); the eighth and last congress to be held before the first world war took place at Washington and New York in 1912, where 4400 chemists, divided into 23 sections, took part and 789 memoranda were discussed. Thus it is for more than fifty years that chemists have been trying to encourage international meetings.

However, the associations which had until then assured the success of these congresses decided that their organization should devolve upon the Union, and the first statutes, in some twenty articles, establish their constitution. The present ruling, which is deliberately less complicated, states that International Congresses of Pure and Applied Chemistry should in principle be held once every four years, and their organization is entrusted to a committee established by the country in which they are to take place; this committee draws up the programme in collaboration with a commission delegated by the Council of the Union.

CONCLUSION

In concluding this summary, mention should be made of the extremely sympathetic atmosphere in which the discussions, the meetings, and the communications of the Union have taken place. We should also emphasize the slenderness of the resources which so far have been available for creating this 'World Parliament of Chemistry.' It has been above all the work of disinterested men, inspired by an ideal. UNESCO is at this moment considering the scope which in the future should be given to international scientific unions. May it furnish them with powerful means, for they are not a negligible factor in the effort to secure that universal peace desired by all men of good will.

Plant cancer

R. J. GAUTHERET

For some time biologists have suspected that an analogy existed between plant tumours and animal cancers, but only recently has it been possible, by use of the method of tissue culture, to establish this analogy. This technique has revealed for the first time that certain bacteria, or substances belonging to the family of heteroauxins, provoke in plants tumourous phenomena similar to those characteristic of cancer. This article is a review of the most recent work in this field, and of the ideas which it suggests for future progress.

NEOPLASMS

Imagine in an organism a cell which, after having functioned for months or years in harmony with the myriads of other cells, suddenly becomes capable of multiplying in a disorderly manner. This cell will give rise to a mass of tissue with abnormal structure: that is, to a tumour. Sometimes the proliferation will be slow and limited; the tumour then produces no important functional disturbances, and remains of a mild character. The warts and wens common in man, and the galls produced on the leaves of many plants by certain insect larvae (figure 1), belong to this type of tumourous growth. If, however, the cellular multiplication becomes completely disorganized, the tumefacient elements may invade the organs of the individual like parasites, and provoke grave and often fatal disorders. These malignant neoplastic developments are known as cancers.

ANIMAL CANCER

Animal cancers have for a long time attracted the attention of biologists, but their nature is still very obscure. Cancer is thought to be a disease of the cell itself. It is not transmitted from cell to cell, but spreads from one organ to another by metastases, that is, by cells which detach themselves from the original tumour and are carried by the blood-stream or the lymph to distant points, where they start new cancerous centres.

This method of propagation shows that the cancerous cell is an element endowed with special properties. The study of tissue culture has thrown some light on the nature of this specificity, showing that the cancerous elements have fewer nutritive needs than the corresponding normal cells. It looks as if the cancerization consists in an increase in the synthesizing power of the cells, which results in unlimited multiplication at the expense of the nutritive substances in the organism. Further investigations on the cause of cancer have shown that it is not of bacterial origin, and have revealed the frequent intervention of carcinogenic viruses and the occurrence of tumourous phenomena produced by physico-chemical processes, e.g. by the action of certain hydrocarbons and other substances, and of certain radiations. It is also obvious that genetic factors play an essential part in the development of cancer, because within a given animal species certain lines of descent are susceptible to cancer, while others, though related, are completely immune.

The fact that tumefaction often requires the simultaneous action of several factors has prevented the welding of the ideas suggested by these discoveries into a single theory. Thus, certain cutaneous cancers of the rabbit require the combined action of a virus and one of the carcinogenic hydrocarbons. The case of the mammary tumour of the mouse is still more complex, because this neoplasm occurs only by the co-ordinated action of definite genetic characteristics, a virus transmitted by the milk (lacteal factor), and a sufficient quantity of oestrogenic hormone.

CROWN-GALL

About forty years ago, two American phytopathologists, Smith and Townsend, suggested that the study of plant tumours would furnish data that might throw some light on the problem of animal cancer. Their attention was attracted by crown-gall, a luxuriant tumour which sometimes develops on certain plants. From this tumour they isolated a rod-bacterium, *Phytomonas tumefaciens*, which when inoculated into healthy plants produces new tumours (figure 2). It therefore seemed out of the question that crown-gall could be in any way similar to animal cancers, since these were certainly not of bacterial origin. Smith nevertheless tried to establish some relation, based on the fact that plants afflicted with crown-gall produce metastases analogous to those produced

by animal cancers. Curiously enough, these metastases do not involve bacterial cells, and it thus seems possible that they result from some action at a distance exercised by the *Phytomonas* contained in the original tumour (figure 3).

Experiments performed about ten years ago seemed to confirm this view, showing that *Phytomonas tumefaciens* synthesizes indoleacetic acid (Berthelot and Amoureux), a substance capable of stimulating the multiplication of plant cells (figure 4). This substance might accumulate in the tissues to a concentration of the order of 10^{-7}, which is sufficient to produce an active proliferation of the cells. It would later diffuse into the tissues around the original centre, which explains the formation of secondary tumours without the direct agency of bacteria.

In view of these results it was not possible to attribute a particular specificity to the cells of crown-gall, and the idea of plant cancer was therefore dropped.

THE CANCEROUS NATURE OF CROWN-GALL

However, two American biologists, Braun and White, reluctant to accept this simple explanation of the tumourous phenomena produced by the *Phytomonas*, went further into the question and compared the physiological properties of crown-gall cells with those of normal elements from similar plants, using the method of tissue culture.[1] They isolated fragments of secondary tumours which, as stated above, do not contain bacteria, and tried to cultivate them in a medium containing mineral salts, a sugar, and traces of glycine and vitamin B_1. The attempt was successful, for by this method they obtained a strain capable of multiplying indefinitely (figure 5). In spite of the absence of *Phytomonas*, these tissues retained their tumourous characteristics in the culture, and when grafted on to a healthy plant they produced new tumours (figure 6). It thus became obvious that the action of the bacteria of crown-gall is simply that of starting the tumourous processes, and these persist without the aid of bacteria. The crown-gall may therefore be considered as a true cancer.

COMPARISON OF CROWN-GALL CELLS AND NORMAL CELLS

In spite of this work, the problem of plant cancer remained unsolved. Braun and White did not compare the physiological properties of cancerous cells with those of normal cells, for they were unable to cultivate normal tissues. In order to solve the problem we undertook the cultivation of crown-gall tissues of several species, such as viper's grass (*Scorzonera*) and Jerusalem artichoke, of which we already knew how to cultivate the normal tissues. In attempting to determine the exact nutritive requirements of these two types of culture, it was found that the media used for cultivating tumourous tissues which contain no growth-promoting substances become capable of sustaining the proliferation of normal tissues by addition of indoleacetic acid. In order to elucidate the significance of this difference in behaviour between normal and tumourous tissues, our student Mlle Kulescha analysed the growth substances or auxins synthesized by the two types of tissue. She found that while normal colonies produce only an insignificant quantity of auxin, which, expressed in indoleacetic acid content, corresponds to a concentration of $0{\cdot}1–0{\cdot}3 \times 10^{-8}$, the concentration in cultures of bacteria-free crown-gall tissues is of the order of 5×10^{-8}, sufficient to activate the cell multiplication. As a result of these experiments it is clear that the tumefaction consists in the intensification of the power of the cells to synthesize the auxins which are essential factors in their multiplication. They thus become capable of multiplying indefinitely in the parenchymatous tissues of the normal plant, even when these are poor in auxins.

[1] ENDEAVOUR, 7, 75, 1948.

MECHANISM OF TUMEFACTION

These investigations did not, of course exhaust the problem of crown-gall, as they did not provide any indication of the mechanism of the tumourous transformation. In order to understand this, it is necessary in the first place to explain how the modifications produced by *Phytomonas* can persist after the elimination of the bacteria. It might be assumed that the bacteria produce a permanent transformation of the cells, with the effect of intensifying the synthesis of auxins, but it then becomes necessary to explain how the bacteria can act in this manner.

CHEMICAL THEORY

Various experiments suggest that in the first place this transformation might be due to the indoleacetic acid manufactured by the *Phytomonas*. We have in fact shown by experiment that by submitting normal tissue cultures to suitable doses of indoleacetic acid over a period of several years they can sometimes be made to acquire the properties of tumourous colonies. This tumourous

FIGURE 1 – *Galls produced on an oak leaf by a hymenopter larva. This neoplasm develops only slightly, and thus has a mild character.*

FIGURE 2 – *Crown-gall developed on a stem of pelargonium. This exuberant tumour is produced by inoculation with* Phytomonas tumefaciens *bacteria.*

FIGURE 3 (*left*) – *Production of metastases by crown-gall. This photograph shows the stalk of a sunflower, which has been inoculated with* Phytomonas tumefaciens. *A tumour developed in the infected area (below); and later, secondary tumours appeared on a leaf some distance from the original source (top left). These secondary tumours were without bacteria (Braun and White).*

FIGURE 4 (*below*) – *Fragment of a root of* Hyoscyamus, *which has been cultivated in a medium containing indoleacetic acid in a concentration of* $1 : 10^6$. *It has produced a large parenchymatous protuberance under the action of the growth-promoting substance. The aspect and structure of this protuberance are analogous to those of neoplasms produced by crown-gall bacteria. However, as is shown later, the physiological characteristics of these neoplasms produced by indoleacetic acid are different from those of bacterial tumours.*

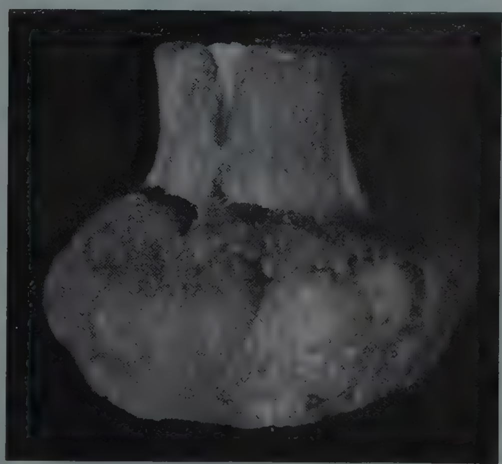


FIGURE 5 – *Culture of crown-gall tissues of the sunflower. This depicts an aseptic culture emanating from a secondary tumour free of* Phytomonas. *The colony shown in this illustration was derived from a strain which had undergone several explantations. (Braun and White.)*

FIGURE 6 – *A tumour obtained by grafting an aseptic culture of crown-gall on to a sunflower stalk. (Braun and White.)*

FIGURE 7 – *Culture of a normal tissue of viper's grass* (Scorzonera) *from a strain subjected to several explantations. These tissues manufacture only an insignificant quantity of auxins, and are therefore unable to multiply without indoleacetic acid. If grafted on to root fragments they do not develop. The colony depicted in the illustration is opaque and compact.*

FIGURE 8 – *Culture of crown-gall tissues of viper's grass. This colony synthesizes a sufficient quantity of auxin to allow it to multiply in a medium without growth-promoting substances. When grafted on to a fragment of a normal root it can develop and produce a tumour. This colony has a translucent appearance.*

FIGURE 9 – *Tumourous colony from a normal stem of viper's grass tissues which has been treated for a prolonged period with indoleacetic acid. This stem has acquired the ability to produce a large quantity of auxins, and for this reason it is capable of multiplying without their addition. When grafted on to fragments of normal roots it is able to produce tumours. It is translucid like the crown-gall tissues, instead of opaque like a normal colony.*

transformation, produced by chemical processes, sometimes occasions sectorial mutations looking like those observed in yeast colonies. It manifests itself in the production, on the surface of a normal colony, of a translucent nipple, which can be transferred separately, thus supplying colonies of a new type with tumourous characteristics (figures 7, 8, and 9). These colonies manufacture auxin of a concentration comparable with that of crown-gall tissues (this corresponds to 3×10^{-8} of indoleacetic acid), giving them the power of multiplying vigorously in a medium lacking heteroauxins. In addition, they produce tumours when grafted on fragments of normal plants. Tissues transformed in this way are therefore similar to crown-gall tissues, and it seems plausible that, as stated above, the indoleacetic acid secreted by the *Phytomonas* is the direct cause of the tumefaction produced by this bacterium.

CRITICISM OF THE CHEMICAL THEORY

This theory, however, is not fully satisfactory. Several facts indicate that there is not likely to be any similarity between chemical and bacterial cancerization. The latter acts almost instantaneously and in a constant manner; to obtain it the *Phytomonas* need be present in the tissues for only ten hours, whereas the carcinogenic action of indoleacetic acid is very slow. A tissue may be treated with indoleacetic acid for many months or even several years and still keep its normal characteristics; then it may suddenly manifest tumefaction—this rarely happens, but when it does the action is very quick.

Bacterial cancerization is therefore an inevitable phenomenon, in which the *Phytomonas* plays a definitely specific part, while chemical cancerization is sporadic: it seems that the indoleacetic acid merely reveals potentialities of tumourous transformations inherent in the tissues. Moreover, this non-specificity of the carcinogenic action of heteroauxins is emphasized by the fact that other heteroauxins can act in the same way.

There are other phenomena that lead to differentiation between bacterial and chemical cancer. Certain plants, for example, do not develop tumours except under the combined action of *Phytomonas* and an external application of indoleacetic acid. This excludes the theory that indoleacetic acid might be the sole factor of the tumourous transformation. Further, the chemical theory provides no satisfactory explanation of certain properties of tumourous tissues, such as the phenomena of tumourous induction discovered by de Ropp and by Camus. When a fragment of a tumourous colony, of bacterial or chemical origin, is grafted on a healthy stump of an organ, it induces the formation of swellings possessing tumourous characteristics. As this action is very rapid it cannot be due to the indoleacetic acid manufactured by the tissues, since this substance is slow-acting. It must therefore be caused by some other factor.

THE VIROLOGICAL THEORY

As the chemical theory of plant cancer leads to serious difficulties, an explanation of tumourous phenomena may be sought in virus action. In the case of crown-gall, for example, the *Phytomonas* might be associated with a carcinogenic virus which survived after the elimination of the bacteria from the tissues. In the case of chemical tumours the carcinogenic virus would be of endogenous origin. This virological hypothesis of plant cancer is evidently only tentative. It is not altogether arbitrary, however, because some viruses are capable of breeding tumours in plants (Black). Furthermore, for the time being it represents the only plausible explanation of the production of cancerous phenomena by grafting.

THE NATURE OF TUMOUROUS TRANSFORMATION

The question of the nature of tumourous transformation remains. This does not arise if the virus theory is accepted, since the sole action of the carcinogenic virus becomes the manufacture of dividing substances, or increasing the synthesizing power of auxins of the contaminated cells. If the virological hypothesis is rejected, another theory must be framed.

For example, there is the possibility of a mutation produced either by bacteria or by indoleacetic acid. This conception is not free from objections; the inevitability characterizing bacterial cancerization does not in fact agree with the possibility of mutation, because this phenomenon is always sporadic. On the other hand, mutation appears more plausible in the case of chemical cancerization, which is a rare and rather irregular phenomenon. Recent observations, however, have shown that there are very numerous grades of intensity of tumourous transformation produced by indoleacetic acid, and this is not compatible with the idea of mutation. It thus appears that the cancerization of plant cells is not a genetic phenomenon, but that it is similar to the enzymatic adaptation so frequent in micro-organisms.

Heredity of pigmented tumours in fish

MYRON GORDON

'The pigmentary system, like all other systems, is subject to aberrations from its normal form, structure, and activity. In particular, neoplastic growths are found in many species of animals . . . in which pigment cells play the dominant role. Among these neoplasms are some of the most malignant tumours known, so that any light that can be thrown upon their origin and behaviour . . . is welcome.'—[Ross G. Harrison, *Biology of Melanomas*.]

Pathologists find that many kinds of tumours are of common occurrence in sharks, fishes, amphibians, reptiles, birds, and mammals [1, 10, 18, 28]. These tumours of vertebrate animals are similar in general structure and essential microscopic details to the corresponding tumours in man [21, 23, 24, 31, 32]. Appreciation of the similarities will be helpful in the interpretation of the fundamental biological nature of all neoplastic growths.

Among the newer living tools available to the cancer research worker are fish, which are particularly valuable for studies of normal and atypical pigment cell growth [18]. Pathologists who have studied and compared the black pigment cell tumours in the representatives of the six classes of vertebrates discovered that the melanoblast is the common cell type in the melanomas of all animals, including those of man [6, 19, 22, 24]. The melanoblasts taken from melanomas of living fish, mouse, and man appear to be almost identical when observed in tissue cultures, and thus seen in all their dimensions and in the fine details of cellular structure [20].

The early embryonic source of pigment cells has recently been discovered. In salamanders, birds, and mice conclusive experiments show that they arise from the neural crest [7, 26]. These early pigment cells are characterized by great mobility, and capacity to spread all over the body [7, 26]. In cyclostomes, elasmobranchs, fish, amphibia, and reptiles, the melanophores normally appear in the perineural, pericoelomic, and perivascular areas, as well as in the skin [34]. In birds and in mammals, pigment cells are generally confined to the epidermis, are less common in the dermis, are occasional in the meninges, and are rare in the deeper regions [34]. In man, a melanoma of the pigmented meningeal membrane of the brain has been described [9].

Pigment cells and their chromatic effects have long been one of the favourite subjects for investigators of problems in genetics. This is particularly true in the study of inheritance in fish, for some of these polymorphic species have a great variety of colour patterns [16].

The chromatophores which produce the various colour patterns in the lower vertebrates are generally known by the principal kind of pigment they contain. Thus, colour-bearing cells containing black pigments are called melanophores. Those which bear red granules are erythrophores; those which contain yellow colouring matter are known as xanthophores; and chromatophores containing guanin crystals are termed guanophores [2, 25]. Several kinds of chromatophore may form a single multicellular chromatic unit. Some chromatophores, especially among the fishes, are extremely complex, and a single cell may contain a combination of several colour elements; for example, the xantho-erythrophore has yellow and red pigments. The chemistry of this remarkable chromatophore has recently been determined, and it was found that in the xantho-erythrophores the yellow substance is made up of lutein and zeaxanthin, while the red pigment is erythropterin [12].

Neoplasms developing from melanophores are the commonest type of pigment cell tumour. Melanotic tumours have been found in the wild representatives of eleven orders of elasmobranch and true fishes [18]. However, in swordtails and platyfish no melanomas have as yet been found in over 20,000 carefully examined wild-caught specimens. Yet by genetic methods of breeding, hundreds of melanomas have been induced in the black-spotted hybrid offspring of the laboratory-bred Mexican swordtails and platyfish [3, 4, 5, 17, 18, 22].

Tumours arising from the more colourful of the pigment cells are relatively rare in fishes. In a twelve-year survey of 100,000 fish of the Sea of Japan, only one silvery tumour, a guanophoroma in a greenling, and one greenish tumour, an

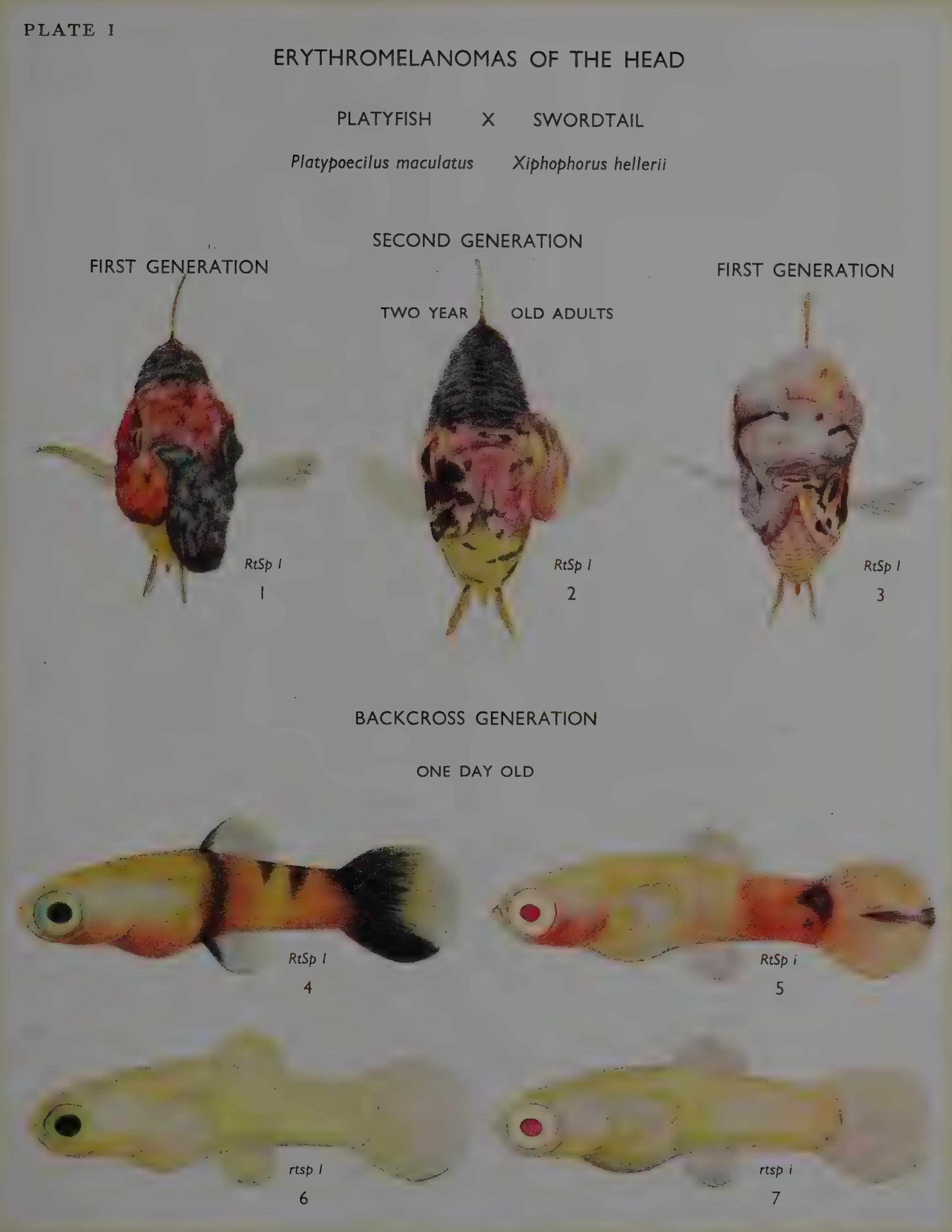


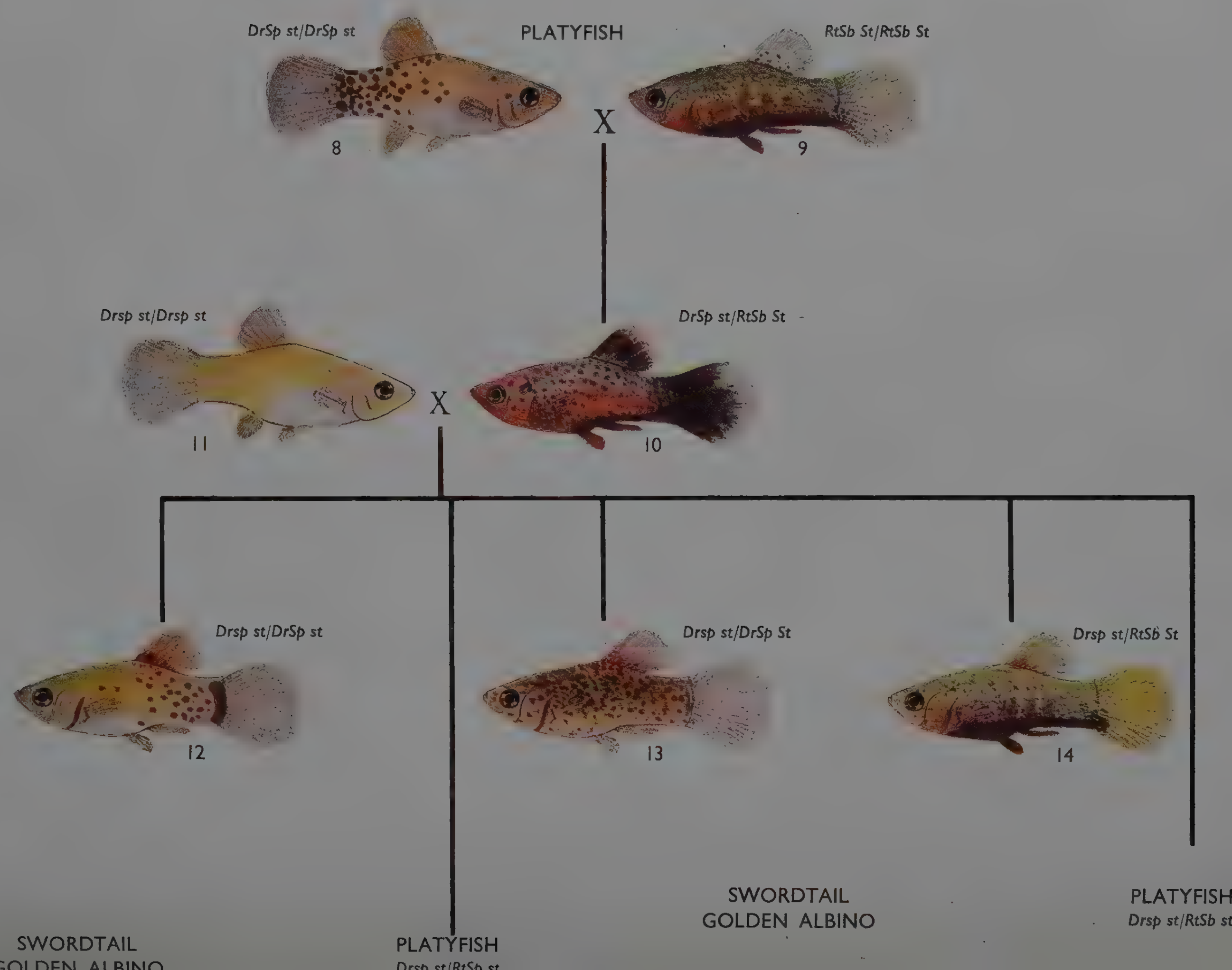
FIGURE 1 – *Head-on view of platyfish-swordtail hybrid number* 206–12 *with erythromelanoma of the head. This individual may be seen in lateral view in figure* 20. FIGURE 2 – *Platyfish-swordtail hybrid, offspring of number* 206–12 *and a normal hybrid. For another second generation hybrid with an erythromelanoma of the head see figure* 23. FIGURE 3 – *Platyfish-swordtail hybrid number* 206–14, *a variation in the form of the erythromelanoma of the head.*

The four phenotypes obtained by mating hybrid number 206–12 *back to a golden, albino swordtail.* FIGURE 4 – *Ruby-throated, spot-sided hybrid with typical coloration.* FIGURE 5 – *Ruby-throated, spot-sided hybrid with* ii *albino genes. Note pink eyes.* FIGURE 6 – *Golden, black-eyed hybrid.* FIGURE 7 – *Golden, albino hybrid. Note pink eyes.*

The outstanding type is the RtSp i (*figure* 5). *Ordinarily the albino gene* ii *inhibits the* Sp *gene's ability to form melanin pigmentation, but in the melanomatous individuals, like the one illustrated here, where* Sp *is in association with* A *and* B, *the melanoblasts in their autonomous growth override the inhibitory effects of* ii *and some black pigmentation is formed.*

PLATE 2

GENETICS OF ERYTHROMELANOMAS



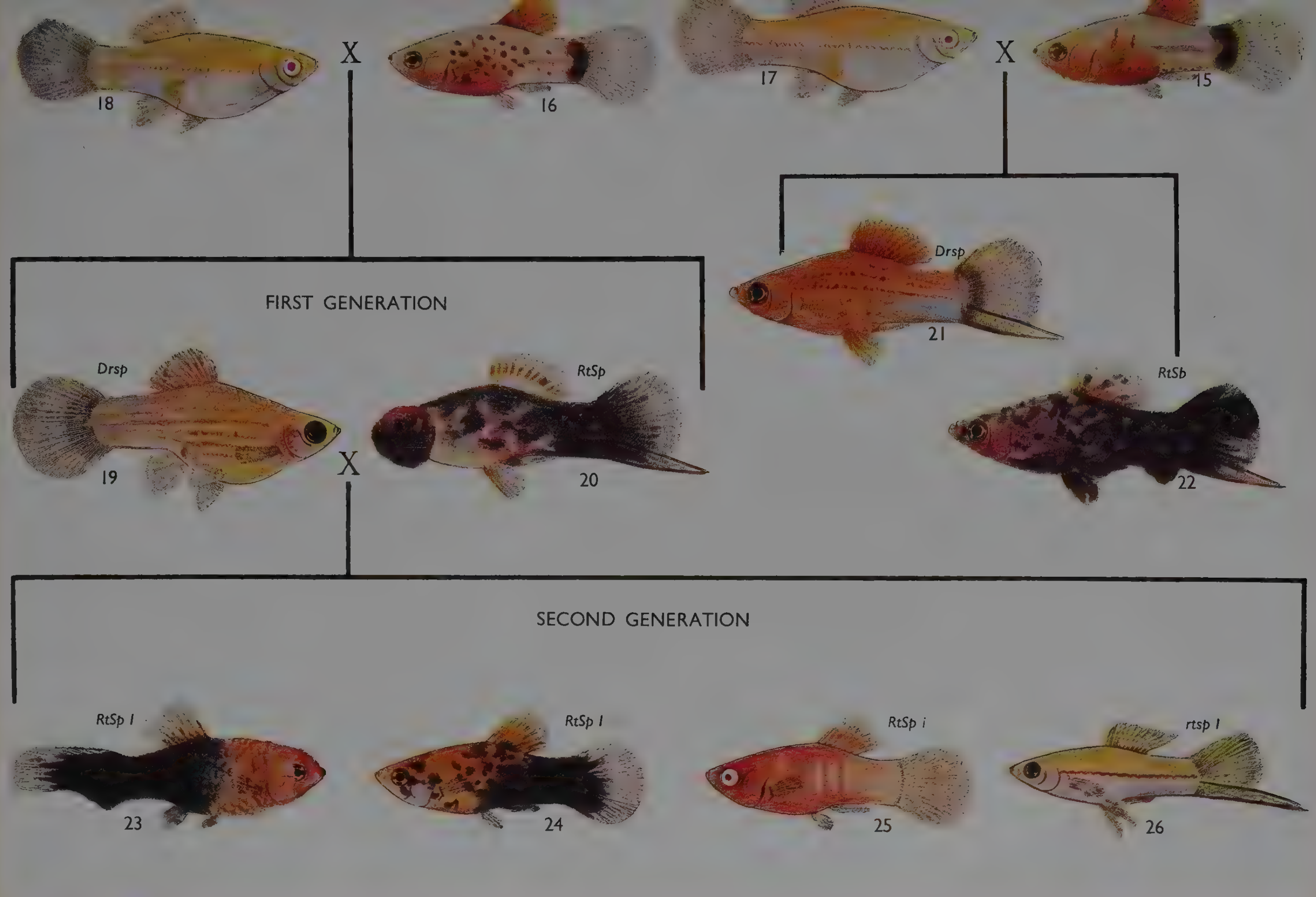


FIGURE 8 – *Golden, red-dorsal-finned, black-spotted platyfish, female.* FIGURE 9 – *Stippled, ruby-throated, spotted-bellied platyfish, male.* FIGURE 10 – *Stippled, red-dorsal-finned, black-spotted, ruby-throated, spotted-bellied platyfish, male.* FIGURE 11 – *Golden, red-dorsal platyfish, female.* FIGURE 12 – *Golden, red-dorsal, spot-sided platyfish, male.* FIGURE 13 – *Stippled, red-dorsal, spot-sided platyfish, male.* FIGURE 14 – *Stippled, red-dorsal, ruby-throated, spotted-bellied platyfish, male.* FIGURE 15 – *Golden, red-dorsal, ruby-throated, spotted-bellied platyfish, male.* FIGURE 16 – *Golden, red-dorsal, ruby-throated, spot-sided platyfish, male (exceptional).* FIGURE 17 – *Golden albino swordtail, female.* FIGURE 18 – *Golden albino swordtail, female.* FIGURE 19 – *Golden, red-dorsal platyfish-swordtail hybrid, normal female.* FIGURE 20 – *Golden, ruby-throated, spot-sided hybrid male with erythromelanoma of the head.* FIGURE 21 – *Golden, red-dorsal platyfish-swordtail hybrid, normal.* FIGURE 22 – *Golden, ruby-throated, spotted-bellied hybrid with melanoma of the mid-ventral line.* FIGURE 23 – *Second generation hybrid with erythromelanoma of the head.* FIGURE 24 – *Second generation hybrid showing melanosis, may develop erythromelanoma when older.* FIGURE 25 *Second generation hybrid albino showing inhibition of melanin pigment. The xantho-erythrophores are not inhibited.* FIGURE 26 – *Second generation hybrid, golden swordtail-like hybrid, normal male.*

FIGURE 27 – *A xantho-erythrophore from* Xiphophorus hellerii. *Photograph of living cell taken by Marian Hedenberg. By courtesy of Dr H. B. Goodrich.* (× 1350)

'allophoroma' in a gurnard, were discovered [31, 32]. In Europe, a xanthoma was reported but once, in a shark [28]. Four erythrophoromas have been discovered among wild fish: in two European trout and a tunny, and in an American winter flounder [29, 33]. Again, in the aquarium-reared fish three erythrophoromas have been detected in the dorsal fin region of golden, red-finned platyfish-swordtail hybrids, and one in a black-spotted red hybrid [8, 22, 30].

Taken all together, the number of red and red-black tumours described in all fishes is only eight. This is exactly the number of cases of red-black tumours that we discovered in one single brood of hybrids born from the mating of a uniquely coloured black-spotted, red platyfish and an albino swordtail (plate 2). Because of the high frequency of these erythromelanomas, the genetic history of the animals was analysed. Before describing our results it would be advantageous to indicate the specific role of the macromelanophores in the development of melanomas in platyfish-swordtail hybrids.

The freshwater Mexican platyfish, *Platypoecilus maculatus*, has more than a hundred black patterns. These are formed from two kinds of melanophore, one large, one small, which are variously arranged upon the body. The *micromelanophores* (controlled by gene *St*) cover the entire surface, and these, together with the underlying xanthophores, give the fish an olive-green grey coloration. The *macromelanophores* (controlled by gene *Sp*) are visible to the naked eye, and these give the fish a spotted appearance.

In a long series of genetic experiments with variously coloured platyfish and swordtails, the *macromelanophore* (*Sp*) was discovered to be the initiating cell in the development of melanomas in the hybrids [16, 17, 18]. The crucial experiment depended upon getting, first, a pure-bred platyfish with macromelanophores (*Sp*) but with no micromelanophores (*stst*) and, second, a swordtail with no melanophores at all (*spsp stst*). A pink-eyed albino swordtail (*ii*) visibly free of melanophores was available, but it was discovered, by testing, that it carried the dominant genetic factor for micromelanophores (*StSt*), the melanin-producing *St* gene being inhibited by the *ii* gene. After some preliminary work a special stock of albinos was

developed which was recessive both for micromelanophores and for albinism (*stst ii*). A female albino swordtail (*stst ii*) was mated with a platyfish male carrying macromelanophores only (*stst Spsp*). This mating may be represented genetically as follows:

Albino swordtail	P_1	*Macromelanophore platyfish*
stst ii spsp	×	*stst II Spsp*

F_1 hybrids

stst Ii Spsp: 20 were deeply black, showing hyperplastic growth of macromelanophores; many developed melanomas.

stst Ii spsp: 29 were yellow-coloured, black-eyed, normal.

This experiment shows that the macromelanophores alone may initiate melanomas in platyfish-swordtail hybrids.

The genetic history of the erythromelanomas which developed in a significant proportion of a single brood of platyfish-swordtail hybrids was traced to a mating between an exceptionally coloured male platyfish and an albino swordtail female. The male platyfish, which had an unusual combination of colour genes, *Rt* for ruby-throated and *Sp* for spot-sided pattern, was obtained as a by-product from a routine series of studies on the genetic mechanisms for sex determination in fish. In that analysis a mating was arranged between two pure-breeding domesticated strains of platyfish [14, 15].

The male grandparent of the exceptional *RtSp* platyfish had the following genes and their corresponding colour patterns (plate 2):

Rt (*ruby-throat*), a sex-linked gene for xantho-erythrophores, an allele of *Dr* (*red dorsal*).

Sb (*spotted belly*), a sex-linked gene for macromelanophores, an allele of *Sp*.

St (*stipple*), an autosomal gene for micromelanophores producing grey body colour.

The female grandparent of the *RtSp* platyfish had the following genes and their corresponding colour patterns:

Dr (*red dorsal fin*), a sex-linked gene for xantho-erythrophores, an allele of *Rt* [11].

Sp (*spotted sides*), a sex-linked gene for macromelanophores, an allele of *Sb* [11].

st, the recessive *stipple* gene producing golden body colour, an allele of *St* [13, 16].

Thus the mating between the red-finned, black-spotted female platyfish and the ruby-throated, spotted-belly male may be represented as follows, where the W indicates a strong female-determining chromosome and the Y indicates the male-determining chromosome in domesticated platyfish stocks [15] (mating number 1; plate 2, figures 8 and 9):

Female	P_1	*Male*
(W)*DrSp st*/(Y)*DrSp st*	×	(Y)*RtSb St*/(Y)*RtSb St*

F_1 Pedigree No. 104

24 daughters: (W)*DrSp st*/(Y)*RtSb St*.

19 sons: (Y)*DrSp st*/(Y)*RtSb St* (plate 2, figure 10).

One of the F_1 males (culture no. 104) was selected and mated to a golden red-finned female of a strain that was homozygous for the *st* and *Dr* genes. This female had two X chromosomes characteristic of the wild platyfish. When a *wild* XX female is mated with a *domesticated* YY male it produces sons but no daughters [15].

The results obtained in the second mating may be expressed genetically as follows (plate 2, figures 10 and 11):

Female	P_1	*Male*
(X)*Drsp st*/(X)*Drsp st*	×	(Y)*DrSp st*/(Y)*RtSb St*

F_1 Pedigree No. 173

28 males: (X)*Drsp st*/(Y)*DrSp St*, red dorsal; spotted sides; olive body colour (figure 13).

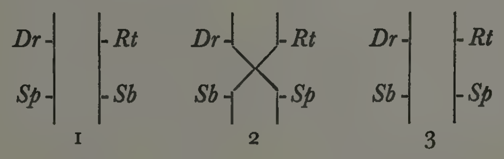
13 males: (X)*Drsp st*/(Y)*DrSp st*, red dorsal; spotted sides; golden body colour (figure 12).

32 males: (X)*Drsp st*/(Y)*RtSb St*, red dorsal; ruby throat; spotted belly; olive body colour (figure 14).

20 males: (X)*Drsp st*/(Y)*RtSb st*, red dorsal; ruby throat; spotted belly; golden body colour (figure 15).

1 male: (X)*Drsp st*/(Y)*RtSp st*, *exceptional cross-over*; red dorsal; ruby throat, spotted sides; golden body colour (figure 16).

The presence of a single exceptional *Drsp st*/*RtSp st* male out of a brood of 94 platyfish may be accounted for by a chance crossing-over of the Y chromosomes of its male parent, which produced a gamete containing the *Rt* and *Sp* genes by a method suggested below:



Crossing-over of the platyfish sex chromosomes, previously reported, occurs at the rate of 1 per cent. [11, 14, 15].

The exceptional ruby-throated, spot-sided *RtSp st*/*Drsp st* male (pedigree no. 173–15) was used in two experiments. It was first mated with an albino swordtail which was recessive for albinism

(*ii*) and for golden (*stst*) indicated as follows: *st i*/*st i* [18]. Since the platyfish, as well as the swordtail, was recessive for golden, the gene *stst* will not be indicated further. *A* and *B* in the albino (see below) represent postulated dominant multiple factors which modify the normal growth pattern of macromelanophores represented by the *Sp* gene [17]. Mating number 3 is as follows (plate 2, figures 16, 18):

Swordtail Female (182–1)	P_1	*Platyfish Male* (173–15)
Albino		Red-finned, ruby-throated spotted sides
A B drsp i/A B rtsp i	×	*a b Drsp I/a b RtSp I*

F_1 Pedigree No. 206

18 *A B drsp i/a b Drsp I*, red platyfish-swordtail hybrids, normal (figure 19).

14 *A B rtsp i/a b RtSp I*, melanotic hybrids, 8 *of which developed erythromelanomas* of the head at two years or more of age (figure 20).

The same exceptional *RtSp st* platyfish male (no. 173–15) was later mated with a golden platyfish (*rtsp st*) of a closely related domesticated strain. This mating (number 4) produced 26 offspring, 11 of which were phenotypically *RtSp st* yet none was abnormal and, of course, the 15 recessive *rtsp st* were normal as well. Subsequent matings within these domesticated (*RtSp st*) platyfish lines have not yet produced any abnormally pigmented individuals in over 300 fishes reared to maturity. Thus the pathological platyfish-swordtail hybrid individuals of culture number 206 must have been produced by the peculiar linked combination of the *RtSp* colour genes of the platyfish with the colour gene modifiers *A* and *B* of the albino swordtail.

When a platyfish-swordtail hybrid male (206–12) with an erythromelanoma of the head was mated to its normal female sibling (206–1) they produced 102 second generation offspring. The results of this mating (number 5) may be represented as follows (plate 2, figures 19, 20, 23, 24, 25, 26):

Female Hybrid (206–1)		*Male Hybrid* (206–12)
Red, normal		Erythromelanoma on head
A B drsp i/a b Drsp I	×	*A B rtsp i/a b RtSp I*

The number of different genotypes possible from the mating (not considering cross-over types) is more than twice the actual number of F_2 hybrids reared. For this reason a detailed genetic analysis of the 102 F_2 hybrids is not practicable. However, the number of *RtSp* animals expected can easily be estimated to be about 50 per cent., or 51 of the total, 102. Actually there were 53 *RtSp* hybrids, of which 11 had unmistakable signs of erythromelanomas of the head. This number (11) was short of the number (39) to be expected if the suggested combination of *RtSp A B* genes alone induces the tumours. Obviously other factors were also involved, but these could not be identified in this experiment. (For some of the phenotypes see plate 2, figures 23, 24, 25, 26.)

There is further indirect evidence that the *RtSp* linkage of genes is necessary for the development of erythromelanomas in hybrid fishes. From the same brood that produced the exceptional *RtSp* male of culture number 173, a sibling male (*RtSb*) with the usual ruby-throated, spotted-belly pattern was chosen and mated to an albino female swordtail of the same culture number as used previously. This mating number 6 may be represented as follows (plate 2):

Swordtail female (182–2)	P_1	*Platyfish male* (173–13)
Albino (figure 17)		Ruby-throated, spotted belly (figure 15)
A B drsb i/A B rtsb i	×	*a b Drsp I/a b RtSb I*

F_1 Pedigree No. 207

14 *A B drsb i/a b Drsp I*, red-finned, red body, normal hybrids (figure 21).

12 *A B rtsb i/a b RtSb I*, all highly melanotic, seven of which developed typical melanomas of the mid-ventral areas at one to two years of age (figure 22).

It is significant that the *RtSb* combination together with *A* and *B* produces melanomas but is incapable of producing erythromelanomas. The *Sb* melanomas are usually found on the ventral areas of the body [18].

One additional experiment (mating number 7) was made in an effort to study the effect of the homozygous albino genes *ii* on the expressivity of the *RtSp* erythromelanomas by means of a backcross as follows:

Swordtail female (182²–6)	P_1	*Hybrid male* (206–12)
Albino		Erythromelanoma
A B rtsp i/A B rtsp I	×	*A B rtsp i/a b RtSp I*

The phenotypes of the offspring (culture no. 241) were as follows:

3 *RtSp i*, red-eyed albinos, 2 with amelanotic melanomas, 1 with no tumour, at six months of age, similar to those figured in plate 1, figure indicated by *RtSp i*.

7 *RtSp I*, typically melanotic, 3 with melanomas at six months of age.

7 *rtsp i*, albinos, red eyes, normal.

7 *rtsp I*, golden, black eyes, normal.

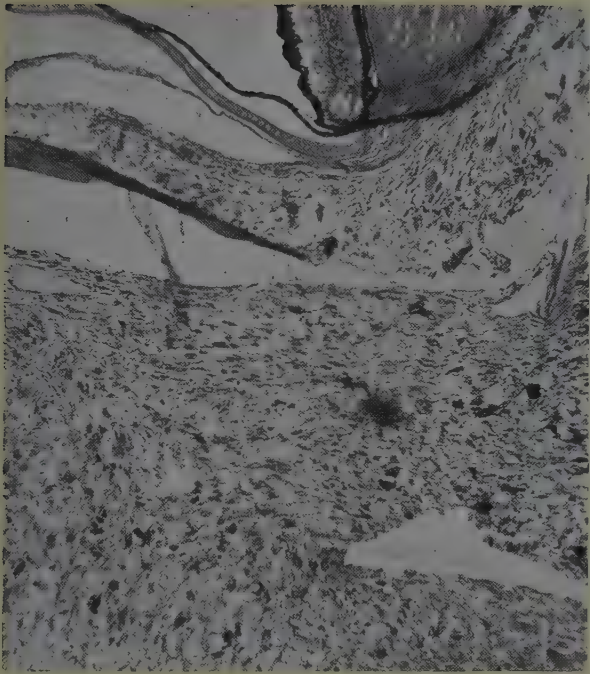


FIGURE 28 – *Cross-section of the erythromelanoma at the level of the eye, under low power. The black spots are macromelanophores and the grey bodies are erythrophores. The entire growth is supported by a well-developed connective tissue reticulum. Note the invasion of muscle, cartilage, and bone of the eye.* (*Haematoxylin and eosin*, × 110)

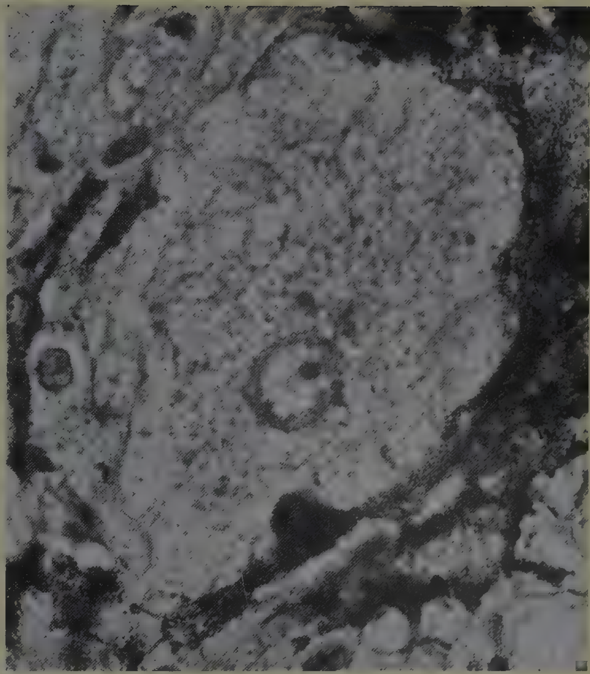


FIGURE 29 – *Cross-section through the erythromelanoma under high power, showing a large erythrophore with its nucleus. This cell is surrounded by several large macromelanophores.* (*Iron-haematoxylin*, × 610)

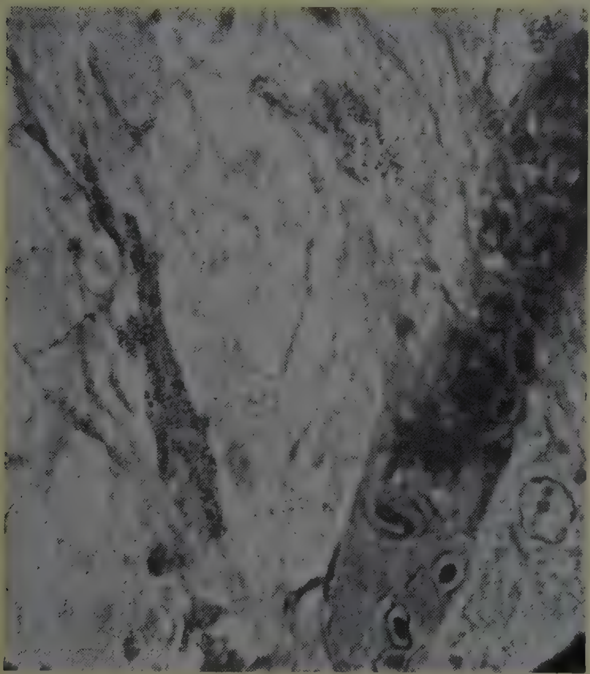


FIGURE 30 – *Cross-section through an erythromelanoma, showing blood-vessel invasion, with an erythrophore cell to the right of the blood-vessel and the highly dendritic macromelanophore to the left of the blood-vessel.* (*Masson*, × 610)

FIGURE 31 – *Cross-section through an erythromelanoma, showing in the upper left-hand corner the destruction of the muscle fibre. A macromelanophore with its nucleus lies in the centre of the figure, and the nuclei of several erythrophores are scattered at various points.* (*Masson*, × 610)

When born, the *RtSp i* hybrids had dark areas of melanin pigmentation on part of their bodies. This is quite remarkable, since they are pink-eyed homozygous recessive for the albino gene. The tumour factors, *Sp* interacting with *A* and *B*, override the albino effect [3, 4, 18]. (See plate 1, Back-cross Generation.)

A study of these genetic data reveals a significant relationship between the spatial association of genes and the effects they produce. The linkage of genes *RtSb* in the platyfish interacting with the *A* and *B* modifying genes of the swordtail determines the development of melanomas in their hybrids. The substitution of *Sp* for *Sb* to produce the *RtSp* linkage, and the introduction of this combination of genes in the platyfish-swordtail hybrid, produce erythromelanomas of the head.

If, however, the genes *Rt* and *Sp* in a platyfish were on separate sex chromosomes, then the ruby-throated, black-spotted platyfish (*Rtsp/rtSp*) when mated with an albino swordtail would produce melanomas rather than erythromelanomas. This would be so because the platyfish would be producing gametes containing *Rtsp* or *rtSp* most of the time. Occasionally the *Rtsp/rtSp* platyfish might be expected to produce an *RtSp* gamete created by a crossing-over of the sex chromosomes. Thus a situation might easily arise in which the genetic constitutions of parents are known in terms of genes involved, and yet unless the spatial relationships of the genes are known also, the results cannot be predicted with complete assurance. These details indicate the importance of studying the various genes and gene combinations and their specific effects upon the growth of specific cells.

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REFERENCES

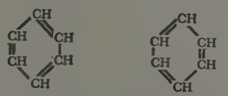
[1] BALL, H. A. *Cancer Res.*, 1946, **6**, 134.
[2] BALLOWITZ, E. *Z. Wiss. Zool.*, 1913, **104**, 471.
[3] BREIDER, H. *Z. Zellforsch.*, 1938, **28**, 784.
[4] *Idem. Z. Wiss. Zool.*, 1939, **152**, 89.
[5] BREIDER, H., and SEELIGER, R. *Ibid.*, 1938, **151**, 243.
[6] DAWSON, J. W. *Edinb. Med. J.*, 1925, **32**, 510.
[7] DUSHANE, G. P. *Biology of Melanomas*, 1948 (N.Y. Acad. Sci., New York).
[8] ERMIN, R. *Rev. Fac. Sci. Univ. d'Istanbul*, 1946, 11, 147.
[9] EWING, J. *Neoplastic Diseases*, 1940 (W. B. Saunders Co., Philadelphia).
[10] FELDMAN, W. H. *Neoplasms of Domesticated Animals*, 1932 (W. B. Saunders Co., Philadelphia).
[11] FRASER, A. C., and GORDON, M. *Genetics*, 1929, **14**, 160.
[12] GOODRICH, H. B., HILL, G. A., and ARRICK, M. S. *Ibid.*, 1941, **26**, 573.
[13] GORDON, M. *Genetics*, 1927, **12**, 253.
[14] *Idem. Ibid.*, 1937, **22**, 376.
[15] *Idem. Ibid.*, 1947, **32**, 8.
[16] *Idem. Amer. J. Cancer*, 1931, **15**; 732, 1495.
[17] *Idem. Ibid.*, 1937, **30**, 362.
[18] *Idem. Biology of Melanomas*, 1948 (N.Y. Acad. Sci., New York).
[19] GORDON, M., and SMITH, G. M. *Amer. J. Cancer*, 1938, **34**, 255.
[20] GRAND, C. G., GORDON, M., and CAMERON, G. *Cancer Res.*, 1941, **1**, 660.
[21] HADDOW, A., and BLAKE, I. *J. Path. Bact.*, 1933, **36**, 41.
[22] KOSSWIG, C. *Z. induct. Abstamm.-u. VererbLehre.*, 1929, **52**, 114.
[23a] LUCKÉ, B., and SCHLUMBERGER, H. G. *J. tech. Meth.*, 1942, **22**, 4.
[23b] *Idem. Physiol. Rev.*, 1949, **29**, 91.
[24] NIGRELLI, R. F. *Trans. N.Y. Acad. Sci.*, 1938, (2), **1**, 4.
[25] PARKER, G. H. *Animal Colour Changes and their Neurohumours*, 1948 (Cambridge).
[26] RAWLES, M. E. *Physiol. Zoöl.*, 1947, **20**, 248.
[27] REED, H. D., and GORDON, M. *Amer. J. Cancer*, 1931, **15**, 1524.
[28] SCHMEY, M. *Frankf. Z. Path.*, 1911, **6**, 230.
[29] SMITH, G. M. *Amer. J. Cancer*, 1934, **21**, 596.
[30] SMITH, G. M., COATES, C. W., and STRONG, L. C. *Zoologica*, 1936, **21**, 219.
[31] TAKAHASHI, K. *Z. Krebsforsch.*, 1929, **29**, 1.
[32] *Idem. Proc. Fifth Pacific Congress*, 1934, **5**, 4, 51.
[33] THOMAS, L. *Bull. Ass. Franç. Cancer*, 1931, **20**, 703.
[34] WEIDENREICH, F. *Z. Morph. & Anthr.*, 1912, **2**, 59.

Cyclo-polyolefines and related molecules

WILSON BAKER

In this article Professor Wilson Baker describes recent developments in our knowledge of certain cyclic conjugated compounds other than those which are benzenoid in character. These include such interesting compounds as tropilone, the azulenes, and various cyclic meso-ionic substances. Recent research has shown that many of the last class of compounds had been wrongly formulated; for some, no single formula is adequate.

Benzene has been regarded as the parent hydrocarbon of the aromatic series since the beginning of systematic organic chemistry; it was originally formulated by Kekulé in 1865 as *cyclo*-hexatriene (figure 1). Seven years later, in order to avoid the difficulty of the non-existence of isomeric *ortho*-disubstituted benzenes, Kekulé suggested that the double bonds oscillated between the two possible positions. Benzene is now known to possess a single structure which may be considered as a hybrid of the two *cyclo*-hexatrienes; in this single structure the conjugated double bonds have interacted to produce six equal carbon-carbon links which have a length of 1·39 A, a value intermediate between that of a carbon-carbon single bond (1·54 A) and a carbon-carbon double bond (1·34 A). The interaction of the bonds brings about a considerable stabilization of the molecule, and calculations based either upon heat of combustion or upon heat of hydrogenation (Kistiakowsky) show that the heat of formation of benzene is some 39 kilogram calories per gram molecule more than that of the hypothetical molecule of *cyclo*-hexatriene with non-interacting double bonds.



Cyclo-*hexatriene* Cyclo-*hexatriene*

Benzene

FIGURE 1

This extra heat of formation, usually referred to as the resonance energy, confers a stability on the molecule which could not be expected of *cyclo*-hexatriene. It also causes benzene to behave chemically in the majority of its reactions as a saturated compound which reacts by substitution, rather than as an olefine which normally reacts by addition. It has long been a matter for conjecture whether other cyclic conjugated olefines such as *cyclo*-butadiene or *cyclo*-octatetraene (figure 2) would possess the typical aromatic characteristics of stability and a high degree of saturation, and it is now seen that, if so, the double bonds of the conjugated systems must be capable of a high degree of resonance interaction. It is, moreover, an essential for resonance that the molecule should be planar; this is because the forms which may be regarded as contributing to the hybrid must possess almost exactly the same relative positions of the atoms, and if, for reasons of strain, this is not possible, then the molecule will not be aromatic but will behave as a *cyclo*-polyolefine. The conditions for resonance are clearly fulfilled by *cyclo*-hexatriene, which becomes the single molecule of benzene.

Cyclo-*butadiene* Cyclo-*octatetraene*

FIGURE 2

In the case of *cyclo*-butadiene, although the molecule would in any case be expected to be flat, the internal angles of 90° are far from the natural C═C—C angles of 120°, and the strain thus set up might more than compensate for the resonance energy. *Cyclo*-butadiene cannot, therefore, be expected to exhibit aromatic characteristics, and may indeed be too unstable to exist.

The molecule of *cyclo*-octatetraene, if planar, would require internal angles of 135°, so that considerable strain would be set up, and a position of compensation is doubtless reached when a further gain in stability due to resonance is offset by a decrease in stability due to strain.

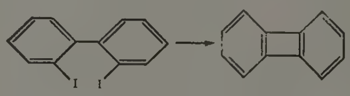
It is the object of the present article to describe some of the recent developments in our knowledge of certain cyclic conjugated compounds other than those which are formally benzenoid in character.

CYCLO-BUTADIENE AND DIPHENYLENE

Early attempts by Willstätter [1] to prepare *cyclo*-butadiene by removal of hydrogen bromide from 1:2-dibromo*cyclo*butane resulted in the production of acetylene, open-chain compounds, and

1-bromo*cyclo*butene-1. A more ambitious attempt by Buchmann in 1942 [2] involved the exhaustive methylation of 1:2-di-dimethylamino*cyclo*butane, but the products were all derivatives of either *cyclo*-butane or *cyclo*-butene. The conclusion may be drawn from these experiments that *cyclo*-butadiene is unlikely to be a stable compound of aromatic character, and this is consistent with the considerations already set out.

The only known compounds which may be regarded as derivatives of *cyclo*-butadiene are the remarkably stable diphenylenes (figure 3). Diphenylene itself was prepared by Lothrop in 1941 [3] by heating a mixture of 2:2′-di-iododiphenyl with cuprous oxide, and homologues were prepared in a similar manner.



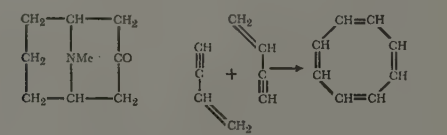
2:2′-Di-iododiphenyl *Diphenylene*

FIGURE 3

Diphenylene crystallizes in pale yellow prismatic needles, m.p. 110°, and readily forms a scarlet picrate. Owing to its inaccessibility, its chemical properties have been little investigated, but on catalytic reduction in alcoholic solution in presence of Raney nickel it gives diphenyl in high yield, thus indicating a considerable strain in the four-membered ring. Diphenylenes are the only compounds known which possess a four-membered ring fused to an aromatic nucleus.

CYCLO-OCTATETRAENE AND DERIVATIVES

Cyclo-octatetraene was first prepared by Willstätter in 1911 [4] from the alkaloid pseudo-pelletierine (figure 4), which contains a bridged *cyclo*-octane ring. Many steps, not all of an unambiguous character, were involved in the preparation, and the final product, a yellow, unstable, unsaturated hydrocarbon, C_8H_8, was not universally accepted as being *cyclo*-octatetraene. This synthesis from pseudo-pelletierine



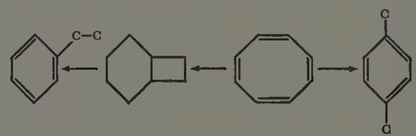
Pseudo-pelletierine *Vinylacetylene* → Cyclo-*octatetraene*

FIGURE 4

has, however, recently been repeated [5], and Willstätter's work was confirmed in all essentials.

A very remarkable synthesis of *cyclo*-octatetraene was achieved by Reppe [6] in the course of an extensive investigation of the synthetical possibilities of acetylene. Reppe showed that acetylene could be safely handled on a large scale, in specially constructed apparatus, under pressures of up to thirty atmospheres, and found accidentally, during an attempt to effect its combination with ethylene oxide, that at 10–20 atmospheres in tetrahydrofuran, in presence of nickel cyanide, it gave *cyclo*-octatetraene in over 70 per cent. yield. With regard to the production of *cyclo*-octatetraene rather than benzene, it is tempting to suggest that it may result from the dimerization of vinylacetylene on the catalyst surface; the linear arrangement of three of the carbon atoms in vinylacetylene may account for the ease of formation of the eight-membered ring (figure 4).

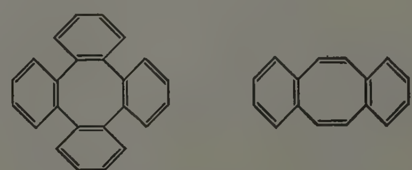
In its chemical properties, *cyclo*-octatetraene behaves as a highly reactive, unsaturated polyolefine, showing no aromatic properties and having only a small resonance energy of 12 kilogram calories per gram molecule [7]. These properties are consistent with its known non-planar structure with alternate double and single bonds; the molecule most probably possesses the 'tub' form, the olefinic groupings being all of the *cis* type [8]. *Cyclo*-octatetraene is readily reduced to either *cyclo*-octane or *cyclo*-octene; the latter gives an excellent yield of suberic acid on oxidation. The instability of the *cyclo*-octatetraene ring is shown by the ease with which it is converted into benzene derivatives by extrusion of two



Derivative of ethylbenzene Bicyclo-(0:2:4)-*octane* Cyclo-*octatetraene* *Derivative of* p-*xylene*

FIGURE 5

carbon atoms to give derivatives of either ethylbenzene or *p*-xylene. An example of the former type is its immediate conversion by aqueous

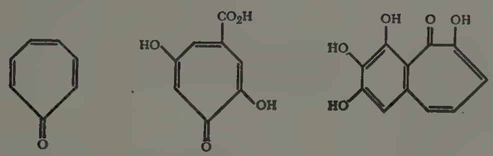


Tetraphenylene Symm.*dibenz*cyclo-*octatetraene*

FIGURE 6

mercuric sulphate into phenylacetaldehyde, and an example of the latter type is the formation of terephthalaldehyde by treatment with alkaline hypochlorite. *Cyclo*-octatetraene is also converted into derivatives of bi*cyclo*-(0:2:4)-octane, for example by the action of chlorine or sulphuryl chloride, and this bicyclic type may be involved in the formation of derivatives of ethyl benzene (figure 5).

Tetra- and tribenz*cyclo*-octatetraenes have been prepared [9]; the former has a buckled eight-membered ring [10], which does not contribute to the ultra-violet absorption of the molecule, and appears to be merely a hole enclosed by the four benzene rings; indeed, its alternative name, tetraphenylene, conveys a more accurate picture of its structure. In symmetrical dibenz*cyclo*-octatetraene [11], the eight-membered ring shows no aromatic properties, the two —CH:CH— groups exhibiting the usual olefinic unsaturated character (figure 6).



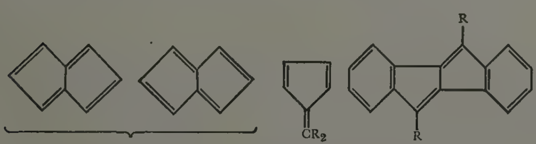
Tropilone *Stipitatic acid* *Purpurogallin*

FIGURE 7

A very interesting type of molecule which is partially aromatic in character has recently attracted considerable attention. This is represented by the substance tropilone (figure 7), which contains three conjugated double bonds in a seven-membered ring, in conjugation with a carbonyl double bond outside the ring. This structure probably occurs in stipitatic acid [12], in the alkaloid colchicine [13], in purpurogallin (an oxidation product of pyrogallol) [14], and other natural compounds.

BICYCLIC SYSTEMS

Certain bicyclic conjugated olefinic systems which contain rings with an odd number of carbon atoms form further types of potentially aromatic compounds. The simplest of these, pentalene, is unknown, but would consist of two fused five-membered rings [15] (figure 8); it should satisfy the conditions previously set out as necessary for the possession of aromatic properties. Two identical Kekulé-like structures are possible; these would be planar and not highly strained, and they bear a close resemblance to the fulvenes, which contain a conjugated system of two cyclic and one exocyclic double bond and are, so far as is known, only weakly aromatic in character. It seems improbable, however, that simple pentalenes would possess a high degree of aromatic character, because attempts to effect dehydrogenation of 0:3:3-bi*cyclo*-octane (octahydropentalene) were unsuccessful [16] under reaction conditions which readily brought about the conversion of decalene into naphthalene. The only derivatives of pentalene yet described are a few dibenzopentalenes (figure 8, where R stands for Cl or Ph) [17], and it seems that in these compounds the pentalene system is stabilized by fusion with the benzene rings, just as the *cyclo*-butadiene ring is stabilized in diphenylene. Benzopentalene (*cyclo*-pentindene) is isomeric with diphenylene, but has not yet been prepared [18].

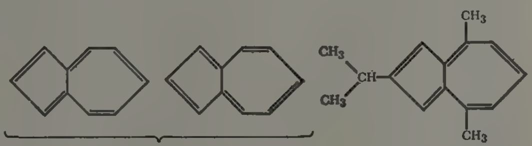


Pentalene *A Fulvene* *Dibenzopentalenes*

FIGURE 8

THE AZULENES

These interesting hydrocarbons are closely analogous to the pentalenes, and possess fused five- and seven-membered rings (figure 9) [19].



Azulene *Vetivazulene*

FIGURE 9

As with the pentalenes, two Kekulé-like structures are possible, and the molecule may be flat and not highly strained. The azulenes have long attracted attention on account of their intense colour, which is usually blue or violet. For example, a 0·1 per cent. solution of azulene itself in a hydrocarbon solvent possesses a fairly deep pure blue colour, so that the minutest traces are at once detectable. Were the azulenes colourless, it is doubtful if we should possess any knowledge of them. Azulenes have been isolated from certain essential oils, and have been prepared by high-temperature dehydrogenation from colourless hydrogenated derivatives contained in the oils; they have also

been prepared by dehydrogenation of synthetic compounds containing the reduced azulene skeleton (derivatives of 0:3:5-bi*cyclo*-decane).

The yields of azulenes obtained by the final dehydrogenations are very small, and these hydrocarbons remain chemical curiosities which have seldom been handled in quantities of more than a few milligrams. Their isolation from both aliphatic and ordinary aromatic compounds is fortunately an easy matter, owing to the fact that they are soluble in 85 per cent. phosphoric acid to give solutions from which the azulene is regenerated by dilution with water [20]. Our knowledge of the chemical behaviour of the azulenes is slight, but it is clear that they possess considerable stability, and like the polycyclic aromatic hydrocarbons they form complexes with reagents such as picric acid and 1:3:5-trinitrobenzene. The resonance energy of the azulene system is 46 kilogram calories per gram molecule [21], compared with the value of 77 kilogram calories for naphthalene, with which it is isomeric.

The structure of the azulenes has been established both by controlled degradation to derivatives of *cyclo*-pentane and *cyclo*-heptane, and by synthesis. Methods employed to build up the reduced azulene ring system have included enlargement of the benzene ring in derivatives of indane by the use of diazoacetic ester, and the Demjanov procedure, whereby a *cyclo*-hexylmethylamine is converted into a derivative of *cyclo*-heptane by the action of nitrous acid. More routine methods of building up the seven-membered ring on to the five-membered ring and *vice versa* have also been employed. The simplest azulene synthesis yet recorded is its production in small quantity by the polymerization of acetylene (Reppe). The naturally occurring azulenes are simple alkyl derivatives of the parent compound; thus vetivazulene is the dimethyl*iso*propyl-azulene shown in figure 9.

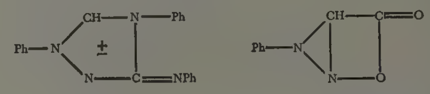
A further possible aromatic system allied to azulene is that consisting of two fused seven-membered rings with six double bonds, but this compound, heptalene, is as yet unknown.

CYCLIC MESO-IONIC COMPOUNDS

The reagent nitron (figure 10; see later for the meaning of the symbol $\pm$) was probably the first to be recognized as belonging to a type of partially aromatic conjugated compound [22], to which the name meso-ionic has since been applied. The general characteristics of this type of compound have been discussed in connection with the structure of the 'sydnones,' a class of compound which was prepared by Earl and his collaborators in the University of Sydney [23]. It was found that the N-nitroso-N-arylglycines,

$$Ar.N(NO).CH_2.CO_2H,$$

gave stable, crystalline, unimolecular anhydro-compounds by loss of one molecule of water when treated with acetic anhydride, and these sydnones were soluble in hydrocarbon and other solvents.

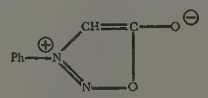


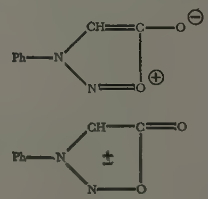
Nitron — N-*Phenylsydnone* (*bicyclic structure*)

FIGURE 10

Hydrolysis with hot alkali regenerated the N-nitroso-N-arylglycines, but boiling with acids caused decomposition to carbon dioxide, formic acid, and an arylhydrazine. The sydnone derived from N-nitroso-α-anilinopropionic acid was similar, but gave acetic acid, carbon dioxide, and phenylhydrazine on hydrolysis. A bicyclic structure (figure 10) was originally tentatively suggested for the sydnones, but, apart from general objections, this formulation is inconsistent with certain facts [24]. The more important of these are that the sydnones do not behave like β-lactones; that optically active sydnones cannot be prepared [25], thus indicating that the CH or CR group is not asymmetrical; that the benzene ring in N-phenylsydnone is chemically inert and thus behaves as if it were attached to a positively charged, rather than to a neutral, nitrogen atom; and finally that the dipole moments of the sydnones are high, being for example 6·6 Debye units in the case of N-phenylsydnone.

There is no possible wholly covalent formula which satisfactorily represents the structures of the sydnones, and their physical properties exclude the possibility that they might be zwitterions





Ionic contributors to the hybrid sydnone molecule (above, left and right)

Sydnone molecule (right), showing symbol to represent their meso-ionic nature

FIGURE 11

with fixed positive and negative charges. An alternative structure has therefore been put forward, in which the electrons of the bridge bond are distributed among the atoms of the sydnone ring, thus giving rise to a single structure which cannot adequately be represented by any one formula employing conventional symbols. The molecule is, in fact, a resonance hybrid, just as benzene is essentially a resonance hybrid of the two Kekulé structures, but in this case it is a hybrid of a large number of contributing forms, all of which are of dipolar or tetrapolar character. Two of these contributors, perhaps the most important, are shown in figure 11, and the symbol $\pm$ indicating the nature of the molecule is also shown. The name meso-ionic is intended to convey the idea that the structure is intermediate between a number of ionic forms. Dipole-moment measurements of sydnones have shown [26] that the nitrogen atom attached to the phenyl group bears a large fractional positive charge, and that the negative end of the dipole is directed towards the oxygen atom of the carbonyl group.

Meso-ionic compounds such as the sydnones belong to a rare type of molecule which cannot be represented, even approximately, by a single covalent structure; or, as in the case of benzene, as a hybrid of a few covalent forms; or, as in the case of the amides, as a hybrid of a covalent and an ionic form, $-\overset{\overset{\displaystyle O}{\|}}{C}-NH-$ and $-\overset{\overset{\displaystyle O^-}{|}}{C}=\overset{+}{N}H-$. The closest analogies are provided by the aliphatic diazo-compounds, which are hybrids of two zwitterion forms $>C{=}N^+{=}N^-$ and $>C^-{-}N^+{\equiv}N$, and the organic azides, which are similarly hybrids of the two forms $R{-}N{=}N^+{=}N^-$ and $R{-}N^-{-}N^+{\equiv}N$. The cyclic meso-ionic compounds are stabilized by resonance, and may therefore be said to be partly aromatic in character, and it may be noted that, for example in the case of the sydnones, many of the contributing ionic forms are very closely allied to partially aromatic five-membered ring compounds such as furan, pyrrole, and oxazole. This aromatic character is reflected in the general properties of the sydnones, in their resistance to catalytic reduction, and in the fact that those with a free CH group undergo substitution as if this group were part of a benzene ring. The aryl group united to the heterocyclic ring is not an essential feature of the sydnone molecule, since both N-benzylsydnone and N-*cyclo*-hexylsydnone are typical members of the class.

There are other types of cyclic meso-ionic compounds in chemical literature, but they have generally been formulated as containing bridged or 'endo' five-membered rings, the majority of which are stereochemically impossible [24].

REFERENCES

General Articles: BAKER. *J. Chem. Soc.*, 258, 1945; *Royal Coll. of Sci. J.*, **18**, 54, 1948.

[1] WILLSTÄTTER and VON SCHMAEDEL. *Berichte*, **38**, 1992, 1905.
[2] BUCHMANN. *J. Amer. Chem. Soc.*, **64**, 2701, 1942.
[3] LOTHROP. *Ibid.*, **63**, 1187, 1941.
[4] WILLSTÄTTER and WASER. *Berichte*, **44**, 3423, 1911; WILLSTÄTTER and HEIDELBERGER. *Ibid.*, **46**, 517, 1913.
[5] COPE and OVERBERGER. *J. Amer. Chem. Soc.*, **70**, 1433, 1948.
[6] REPPE. *British Intelligence Objectives Sub-Committee, Final Report*, **137**, Item 22.
[7] PROSEN, JOHNSON, and ROSSINI. *J. Amer. Chem. Soc.*, **69**, 2068, 1947.
[8] KAUFMANN, FANKUCHEN, and MARK. *Nature*, **161**, 165, 1948.
[9] RAPSON, SHUTTLEWORTH, and NIEKERK. *J. Chem. Soc.*, 326, 1943; SHUTTLEWORTH, RAPSON, and STEWART. *Ibid.*, 71, 1944.
[10] KARLE and BROCKWAY. *J. Amer. Chem. Soc.*, **66**, 1974, 1944.
[11] FIESER and PECHET. *Ibid.*, **68**, 2577, 1946.
[12] DEWAR. *Nature*, **155**, 50, 1945.
[13] *Idem. Ibid.*, **155**, 141, 1945.
[14] BARLTROP and NICHOLSON. *J. Chem. Soc.*, 116, 1948; HAWORTH, MOORE, and PAUSON. *Ibid.*, 1045, 1948.
[15] ARMIT and ROBINSON. *Ibid.*, **121**, 828, 1922.
[16] BARRETT and LINSTEAD. *Ibid.*, 612, 1936.
[17] BRAND *et al. Berichte*, **45**, 3071, 1912; **53**, 809, 815, 1920; **55**, 601, 1922; **69**, 2504, 1936. WAWZONEK. *J. Amer. Chem. Soc.*, **62**, 745, 1940.
[18] BAKER and LEEDS. *J. Chem. Soc.*, 974, 1948.
[19] ST. PFAU and PLATTNER. Numerous papers in *Helv. Chim. Acta*, since 1936. Reviews by HAWORTH. *Chem. Soc. Annual Reports*, **34**, 393, 1937; HARPER. *Ibid.*, **44**, 162, 1947; ARNOLD. *Die Chemie*, **56**, 7, 1943.
[20] SHERNDAL. *J. Amer. Chem. Soc.*, **37**, 167, 1537, 1915.
[21] HEILBRONNER and WIELAND. *Helv. Chim. Acta*, **30**, 953, 1947.
[22] SCHÖNBERG. *J. Chem. Soc.*, 824, 1938.
[23] EARL and MACKNEY. *Ibid.*, 899, 1935; EADE and EARL. *Ibid.*, 591, 1946.
[24] BAKER and OLLIS. *Nature*, **158**, 703, 1946; BAKER, OLLIS, and POOLE. *J. Chem. Soc.*, 307, 1949.
[25] KENNER and MACKAY. *Nature*, **158**, 909, 1946; EARL. *Ibid.*, **158**, 909, 1946.
[26] BAKER, OLLIS, POOLE, BARLTROP, HILL, and SUTTON. *Ibid.*, **160**, 366, 1947; EARL, LEAKE, and LE FÈVRE. *Ibid.*, **160**, 366, 1947; *Idem. J. Chem. Soc.*, 2269, 1948; HILL and SUTTON. *Ibid.*, 746, 1949.

The future of English building-stones

W. J. ARKELL

One of the features of British architecture most striking to the visitor from overseas is the dignity of the age-old stone churches, colleges, houses, and cottages. Modern methods of building, with mass-produced bricks and concrete blocks, threaten to extinguish building in stone, which for centuries has been one of Britain's proudest activities. Dr Arkell explains how scientific investigation may assist to preserve it in spite of such severe competition.

On 17th January, 1949, in London, the Minister of Health pledged himself to co-operate in every way to revive building in stone, which he acknowledged to be 'one of England's most ancient and important activities.' 'It would be a national misfortune if all our building in stone ceased,' he declared; and in the stone districts 'it would be a monstrous outrage to have the red rash of some of the industrial brick.'[1]

Many people in less influential positions have been saying the same thing for many years, but still the costs of stone building rise and still the drain of masons into occupations with better prospects continues. In Oxford and Cambridge, where war-time arrears of repair to stonework and some new buildings have to be undertaken, the colleges have to find several times the money that the same work would have cost before the war.

Yet, notwithstanding the ministerial declarations just quoted, a statement issued on 1st June, 1949, by the council of the Royal Institute of British Architects[2] shows that the real cause of the trouble is Government policy, 'which has, up to now, concentrated on economy in money costs' in house-building, at a time when house-building is given Government priority and almost all other building is held up in consequence. 'True economy,' the statement continues, 'may well dictate a much greater use of stone in state-aided housing.' . '. . . architects have no intention of abandoning the use of stone as a building material' and 'affirm their confidence in the future of the masons' craft.'

There are dangers inherent in a too sudden expansion of stone building. Really durable freestones are by no means common or easy to locate and identify even in stone districts, and long experience is necessary if disasters are to be avoided. The medieval cathedrals and churches which have successfully weathered so many centuries are built of stones that must have been subjected to ruthless selection by masons and quarrymen with lifelong experience. What may happen if short cuts are taken is exemplified by many Oxford colleges and churches built in the seventeenth and eighteenth centuries of local Headington stone. Within a century they crumbled away, and hundreds of thousands of pounds have had to be spent in re-facing them. A similar mistake was made again in the late nineteenth century, when many new buildings were put up in Oxford of another local stone from Milton near Burford. The University church of St. Mary's had to be re-faced and partly rebuilt at great cost twice in forty years, on account of the failure of Milton stone. Yet Milton quarries are close to the famous quarries of Taynton, which yielded stone of great renown for many centuries, and much that still stands in Oxford in structures 500–600 years old. The same happened with Doulting stone from Somerset. The medieval masons knew how to select Doulting stone—for instance for the west front of Wells Cathedral—that would last for 600–700 years; but much Doulting stone from adjacent quarries sent to Oxford between 1870 and 1900 is already badly decayed and will soon need replacement.

The first lesson to be learned is that bedded building stones are so variable in their capacity to resist the weather that, despite identity of geological age and all visible characteristics, it is not good policy to build with stone from random selection on the outcrop of a famous stone bed, or even from quarries close to a celebrated quarry; only the original bed in the original quarry, discovered by the old craftsmen and tested by time, is good enough. Even within a single quarry there are generally important variations in the character

[1] Mr A. Bevan, at the Housing Centre conference, Central Hall, Westminster.—*The Times*, 18th Jan. 1949.

[2] Statement on the use of stone.—R.I.B.A., 66 Portland Place, London, W.1.

FIGURE 1 – *Saxon tower at Brixworth, Northamptonshire, probably built before* A.D. 700. *A virtually everlasting tower built of hard boulders sorted out of the local Glacial Drift, mixed with local ragstone slabs, but without freestone dressings. Except for the pulling down and rebuilding of the upper stage, the tower has had no major repairs. It is a museum of rock types, largely brought by ice from Charnwood Forest.*

FIGURE 2 – *Saxon tower, Earls Barton, Northamptonshire, constructed from random rubble and dressed with hard Barnack Rag, brought about forty miles up the River Nene from the quarries near Stamford. An example of an almost indestructible building which has lasted a thousand years, built without any freestone.*

The pilaster strips are structural ties strengthening the random rubble walls. Some of the ornamental work may be in imitation of wooden construction.

FIGURE 3 – *Council houses, built of the local walling-stone, at Langton Matravers, Isle of Purbeck.*
(*By permission of the editor of* Mercury)

FIGURE 4 – *Some of the Portland stone quarries from the air.*
(*By permission of Dr J. K. St. Joseph*)

FIGURE 5 – (*a*) *Weldon freestone quarries, Northamptonshire, showing tools, and* (*b*) *Weldon quarries, showing blocks of freestone sawn to shape. The quarry adjoins the new steelworkers' town of Corby. It provided stones like these for King's College Chapel, Cambridge, from* 1508 *to* 1515, *and for Clare, Corpus, and Trinity Colleges.*

FIGURE 6 – *Refacing the hall of Trinity College, Cambridge, June* 1949. *Removal of cracked stucco has revealed the original walls* (1604) *of random rubble masonry consisting chiefly of local clunch and Cornbrash limestone from near Peterborough. The wall is being refaced with Ketton freestone.*

of a stone: colour, texture, hardness, and—most subtle but most important—durability. In the light of this it is folly to fill up old stone quarries indiscriminately with rubbish, as has been done by so many authorities all over Britain. A priceless asset has been repeatedly sacrificed in this way to the expediency of the local authority responsible for rubbish disposal. The loss of the quarry and its future potentialities is permanent; the relief of the authority is temporary, for some better method of refuse-disposal will necessarily have to be evolved and standardized in a few years, when all the quarries are full.[1]

Another danger, with a profound bearing on the aesthetic results which are admittedly one of the prime objects of building in stone, is the promiscuous use of stones from different areas solely on account of their proved durability. This danger is especially great now that costs of transport have become such a small proportion of the whole cost of building. Proximity to source of supply has been reduced by motor transport to an almost negligible advantage. Yet it is just the local stamp of the buildings in the stone areas that is the secret of their satisfying quality. To bring ironstone or granite or Mendip limestone into the Cotswolds would be just as 'monstrous an outrage' as to use red brick. On the other hand, other Jurassic limestones from anywhere along the oolite belt, from Dorset to Lincolnshire, blend perfectly with the native Cotswold stones. Clipsham stone looks quite at home in Oxford. Distance has nothing to do with it. In this way, therefore, bad mistakes can be made without any pecuniary advantage, and it is essential that geological knowledge, combined with a modicum of aesthetic sensibility, should be drawn upon by local authorities, both for their own building schemes and for the passing of plans for private schemes.

The most obvious and essential part for science to play, however, is to provide some means of ascertaining the durability of building stones, to replace the lost art of the olden-day craftsman based on natural flair and lifelong experience. This problem has been attacked with considerable success at the Building Research Station at Watford, near London. It is one of those problems that appear elementary but prove to be far from simple. Each kind of stone presents different combinations of characters, which may cause different kinds of failure in response to several varieties of weathering—sometimes predominantly chemical, sometimes predominantly mechanical, but usually a combination of the two. There is no golden rule for all stones. Each kind has to be studied individually.

For Portland stone and some similar oolites the most reliable is the crystallization test. Specimens of standard size are soaked in a 14 per cent. solution of sodium sulphate, and dried in an oven under strict control. The force of crystallization disrupts the weaker stones but not the stronger. Similar effects are produced when rain freezes in the surface layers of some stones. It might be thought that the degree of simple porosity would therefore be a good measure of durability, but this is not so. For instance, Ketton stone, an almost perfect oolite, is one of the most durable of the oolitic stones but at the same time the most porous. When a can of water is poured on a large quarry-dressed block it all soaks in; none runs off.

The reason seems to be that there are two kinds of porosity: macroporosity, due to spaces between the grains of the oolite, and microporosity, due to minute cavities within the grains. Degree of macroporosity seems to have little connection with durability, but microporosity is all-important. By delicate measurements (with a modified capillary method) it has been proved at the Building Research Station that stones of proved durability have the lowest microporosity, and *vice versa*, and the results are consistent with those obtained by the crystallization test. In future, therefore, by taking samples at suitable intervals during building operations, it should be possible to detect subtle changes in a freestone as quarrying proceeds, and to eliminate unsound material. It is essential that responsible authorities should realize that these possibilities exist, and that facilities for carrying out the tests should be available on an adequate scale when stone building becomes more general again.

When stone building is mentioned too many people think only of ashlar. In reality, ashlar masonry, requiring high-class freestone, is only the show-flower of masonry and is never likely to become general. By far the greater part of the stone buildings in Britain—cottages, farms, dwelling-houses, and barns—are built of coursed or random rubble masonry, made from walling-stone dug from small local quarries. These stones are much more generally distributed than freestone, are infinitely more easily quarried and

[1] Thanks to representations through the International Geological Congress in 1948, some quarries have been saved, and at least no authority can now plead ignorance or unawareness of what it is doing. Nevertheless, constant vigilance by the public is necessary.

worked, and are not subject to scaling and decay. They are, moreover, the only kind of stone suitable for the majority of buildings required outside the large towns. It is therefore in the walling-stones and coursed rubble masonry that the future of English stone building lies.

In the west, from Cornwall to Northumberland and in Wales, there is no freestone, yet these districts are all eminently stone ones. The local walling-stone was dug from scores of small quarries wherever a hard rock was available. The same applies also to the Cotswolds and the rest of the main oolite belt, and to the many minor stone districts for which the scenery of England is so justly famed: for instance, the ironstone towns and villages of North Oxfordshire and parts of Northamptonshire; the carstone villages and churches along the Lower Greensand outcrop in Bedfordshire, Cambridgeshire, and Norfolk; the famous grey stone villages of Purbeck, with old Swanage; the coral rag rubblestone villages of North Wiltshire and White Horse Vale, strung out from Calne by Wootton Bassett, Highworth, and Faringdon to Wytham, Old Headington, and Wheatley. These are the core and the real substance of the heritage of rural England, for the continuance of which as a living and developing organism, not a dwindling museum exhibit, the most strenuous efforts should be made.

During the last thirty years, in some districts of which the writer has personal knowledge, the local authorities have been condemning old rubble-walled and stone-slated or thatched cottages to demolition, even when architects have declared that they could be reconditioned and altered to make sound and healthy homes. The small quarries from which the indestructible and beautiful local stones are supplied, having first become disused by reason of the competition of mass-produced bricks and concrete blocks, have been systematically filled up with refuse by the local authorities. Speculative builders after the first war, and local councils after the second, have, with some notable exceptions (figure 3), planted down among the infinitely varied and infinitely vulnerable tissues of the English countryside batches or ribbons of new houses of the most barbarous incongruity and soulless uniformity in layout and materials.

To an outside observer it must seem incomprehensible that, while facilities for education are expanding at an unprecedented rate, this same population is condemning itself and its descendants to spend their lives among dreary, monotonous bricks and concrete, which at the present rate will soon sprawl from one end of Britain to the other.

It is still not too late to save much that is precious, and to redirect our building activities along less negative lines, not subordinated so entirely to temporary expediency. The stone industry is not dead and can be revived. The skill and pride of the masons and the experience and lore of the quarrymen, inherited from countless generations, are dying out but can be saved and carried on. A few miles from the worked-out Barnack quarries, whence the Romans took their milestones and coffins and the Saxons and Normans carried off the great stones for innumerable churches (figure 2), the quarrymen at Weldon still work the beautiful cream-coloured freestone (figure 5). In the adjoining parish of Corby a new town for 40,000 steelworkers is planned. What proportion of these state-aided houses will be built of the local stone that lies so abundantly to hand? Here is an opportunity for a Government-sponsored training centre for masons and quarrymen, who may learn as they work. Or will the opening up of this new town in rural Northamptonshire coincide with the final closing down of the quarries?

So far the signs are that it will. Even the new Council Houses at Clipsham, to house the quarrymen who work the Clipsham quarries, are to be of brick because the Ministry of Health will not sanction the expenditure of more than an extra £133 per house. And unfortunately, although the owner of Clipsham quarries offered the walling-stone free of charge, the additional cost works out at £300 per house.[1] This is due mainly to the extra labour for chopping or rough-dressing the stone, but also to the need for a certain amount of freestone for dressings, and to the necessity for stronger foundations and thicker walls. So for the want of £167 per house, Clipsham village is to have twelve brick homes for its quarrymen, a permanent rent in the pattern and tradition of yet another lovely village on the stone belt.

Such facts as these present a challenge which should be met officially by vigorous research into methods of reducing costs of building in stone. For instance, compressed air has revolutionised quarry-dressing of the freestone at Clipsham quarries; some mechanical means of rough-dressing the walling-stone might also be devised. If the words of the Minister of Health were anything more than mere words, these urgent matters will not much longer be allowed to go by default.

[1] *Manchester Guardian*, 8th October, 1949.

Astronomy in South Africa

DAVID S. EVANS

South Africa has been called the astronomer's paradise, and it certainly has more active observatories for its population than any other region of the world. Circumstances have made it the centre of southern-hemisphere astronomy, and there is good hope for the eventual development of a distinctive South African school of astronomy, the achievements of which may parallel those of the older northern workers. Much has indeed already been done.

The association of astronomy with South Africa is not by any means a recent phenomenon. Centuries ago, the then newly discovered route to India began to make of the Cape of Good Hope a 'refreshment station' for ships and a fixed point in the sketchy processes of early navigation. In 1685 Jesuit missionaries under Father Tachard came to the Cape on their way to Siam, and attempted, as their successors were to do for long afterwards, to fix its longitude. The most notable of the early astronomers in Africa was, however, the Abbé La Caille, who arrived in 1751 and who, in little more than a year, accomplished a remarkable quantity of observational work, including laying the basis for a catalogue of 10,000 southern stars and making observations towards the determination of the solar and lunar parallaxes.[1] In this he foreshadowed much later work, and in addition he initiated a line of research later to be developed out of all recognition, by surveying a short length of the arc of a meridian of the earth's surface.

In those days the Cape was in Dutch hands, but in 1814, by cession and purchase, it was acquired by Britain. In 1820 the Admiralty decided that it would be advantageous to establish a permanent observatory at the Cape for the assistance of navigation, the provision of a time service for ships, and the observation of southern stars not visible from Europe. As a result the Reverend Fearon Fallows became the first of a distinguished line of H.M. Astronomers at the Cape. There he set up his observatory—the buildings of which were completed five years later—on a site to the north-east of Table Mountain from which signals to shipping in Table Bay could readily be sent. The early years were hard: the surrounding country was composed of sand and mud, and stories are extant of hippopotami in a near-by river and of a Cape tiger (leopard) found asleep on the roof shutters of the observatory. Fallows, however, was a worthy founder of a distinguished line.

He was succeeded in 1832 by Henderson, whose short time of one year at the Cape before he resigned for reasons of health was memorable for the observations which provided the first determination of the distance of a star, *Alpha Centauri*. Thomas Maclear, who followed Henderson in 1833, established the Observatory on a firm basis during his long tenure of office of 37 years. He not only made important contributions to the astronomy of the southern hemisphere, but his careful verification and extension of La Caille's arc of the meridian was of great value to geodesy. During Maclear's period of office Sir John Herschel made his well-known expedition to the Cape in the years 1834–8; he erected his father's twenty-foot reflector at Feldhausen, near Cape Town, to sweep systematically the southern skies in the same manner as his father had swept the northern. In the course of these sweeps some 1200 double stars and about 1500 nebulae were discovered; the magnitudes of the brighter stars were determined; and many special observations of interest were made.

The greatest of the successors of Fallows was undoubtedly Sir David Gill. Gill had been a pupil of Clerk Maxwell in Scotland, and after a period as an amateur astronomer had given up a flourishing business to become private astronomer to the Earl of Crawford (Lord Lindsay). It was in this capacity that he had gone to Mauritius to observe a transit of Venus, the results of which, it was hoped, would yield reliable values of the solar parallax. On the same expedition he also made observations which, by links through Aden and

[1] The lunar and solar parallaxes are the angles subtended at the average distances of the moon and sun by a line equal in length to the radius of the earth. These angles are therefore measures of these distances, and their determination fixes the size of the solar system, providing a base line for the determination of all stellar distances.

Durban, were to fix the longitude of the Cape with considerable accuracy.

During Gill's time at the Royal Observatory at the Cape from 1879 to 1907 a prodigious amount of work was carried out. Not only did Gill continue the vast work of cataloguing the southern stars; he also accomplished a revolution in astronomy by the introduction of photography for the determination of star positions. This development originated in the photography of the comet of 1882, undertaken with the aid of a local professional photographer. It led, first, to the Cape photographic *Durchmusterung*, a catalogue in which the positions of not far short of half a million stars were determined, the reductions being carried out in collaboration with Kapteyn, the celebrated Dutch astronomer. A second consequence was the proposal for mapping the whole sky by means of photography, which later took shape as the project for the *Carte du Ciel*, in which the whole sky was to be mapped by observatories all over the world working in concert and using standard instruments. To Kapteyn's interest in this work must in some degree be attributed his discovery of star streaming—the preferential motions in space of the stars near the sun—announced by him at the British Association meeting in South Africa in 1905.

As if this were not enough, Gill also made observations for the determination of solar parallax and of the mass of the Moon, using a heliometer, in the application of which he was an adept. This instrument has a divided object glass, the relative movement of the two halves being used to secure coincidence of the images of two objects the angular separation of which is to be determined. Gill also used the heliometer for the determination of the distances of a number of southern stars, with an accuracy not surpassed until the development of photographic methods, which, requiring much less time at the telescope and much less computational work in deriving the results, have made the heliometer obsolete.

Lastly, it is to Gill that we owe the conception of the project for the survey of an arc of the meridian running right up the African continent and beyond, which would serve to determine the exact figure of the Earth. Even today this project is not complete, but it is astonishing to see the extent of the work done in Gill's lifetime, especially in view of the desolate nature of some of the country traversed—in parts of which work was impossible except when water-melons, representing the only available source of water, were ripe.

It is fitting that Gill's work should be reviewed at some length, not only because of his influence on the scientific history of southern Africa, but also because in his time the Royal Observatory developed tremendously. It was then that the 24-inch Victoria refractor, which is still in use, was acquired as a gift from Frank McClean, and it was also during his tenure of office that part of the work on the photographic charts of the southern sky was done at Cape Town by Franklin-Adams. The traditions which Gill set are still alive. The Royal Observatory is still concerned with fundamental astronomy of the southern sky—the measurement of positions and parallaxes, and more recently of star magnitudes. The determination of the solar parallax by observations of Eros in 1931, in the results of which the Cape observations played an important part, was carried out as an international project under the direction of Sir Harold Spencer Jones, now Astronomer Royal but then H.M. Astronomer at the Cape, and is in the same great tradition. The present H.M. Astronomer, Dr J. Jackson, had the difficult task of piloting the observatory through the war years, but even in face of depleted staff and other difficulties the work was continued and, especially in the field of stellar photometry, extended.

During his tenure of office Gill received a request for employment from a Mr R. T. A. Innes, an Australian amateur astronomer, who gave up business as a merchant in Sydney to come to the Cape, at first in the relatively humble capacity of secretary and librarian. However, Innes proved to be an outstanding observer of double stars, and is now remembered as the author of a standard work on this subject. In 1903 the administration which was set up in the Transvaal after the Boer war established a meteorological observatory in Johannesburg, and Innes was appointed director. At first this institution had no more than a 9-inch telescope, but later, after the formation of the Union of South Africa in 1910, it became the Union Observatory, acquiring, after the first world war, a large refractor of 26½-inch aperture. The Observatory is known particularly for its work on double stars, minor planets, and comets, and it was here that the Franklin-Adams cameras were set up, under the direction of Innes' successor, H. E. Wood, to complete the task of photographing the southern sky. The present Union Astronomer, Dr van den Bos, is also famous as a double star observer, and the Observatory has continued to specialize in the types of work already

FIGURE 1 – *Dome of the 26-inch telescope at the Union Observatory, Johannesburg. (By courtesy of the Union Astronomer.)*

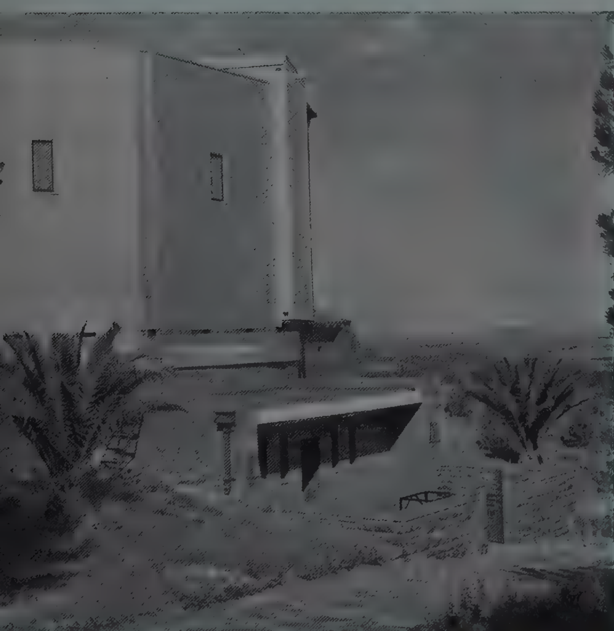


FIGURE 2 – *60-inch Rockefeller reflector turret at the Harvard Observatory, Bloemfontein. (By courtesy of Dr J. S. Paraskevopoulos.)*

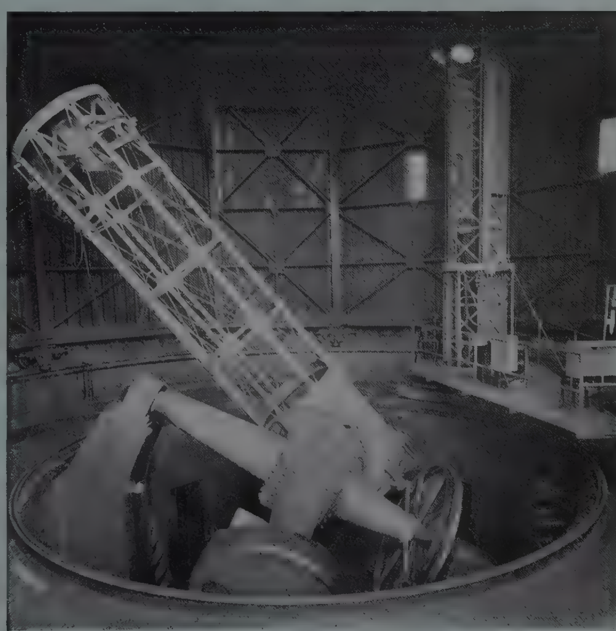


FIGURE 3 – *60-inch Rockefeller reflector at the Harvard Observatory, Bloemfontein. (By courtesy of Dr J. S. Paraskevopoulos.)*

FIGURE 4 – *Dome of the Lamont-Hussey Observatory, Bloemfontein, housing 27-inch refractor.*

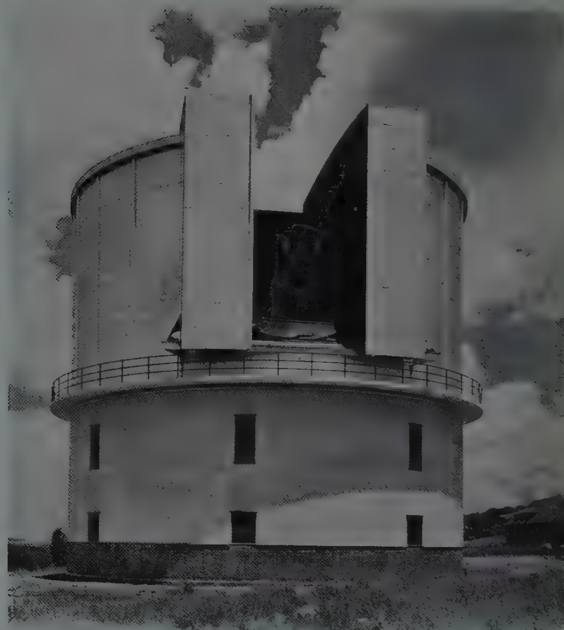


FIGURE 5 – *Turret of the Radcliffe Observatory, Pretoria. (By courtesy of the Director.)*

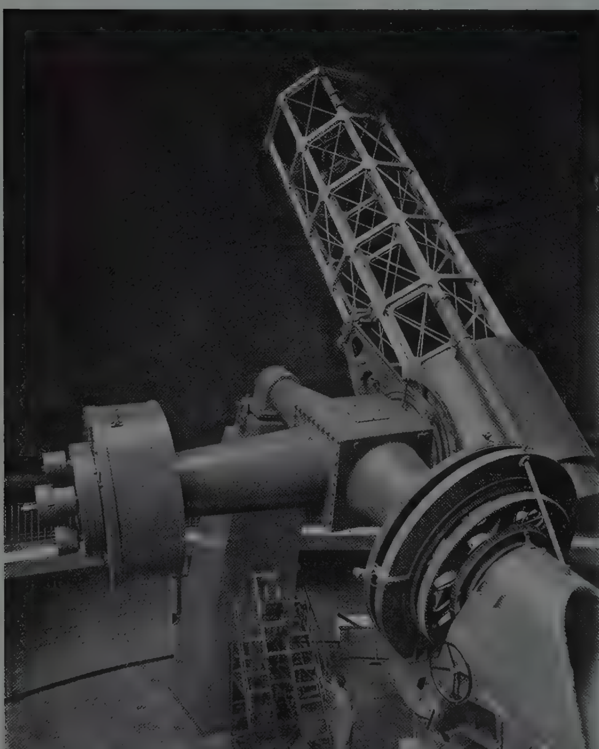


FIGURE 6 – *The Radcliffe reflector. (By courtesy of the Director.)*

FIGURE 7 – *Dome of the Victoria telescope, the Royal Observatory, Cape Town.*

mentioned, as well as providing a time service and interesting itself in seismological work.

The Cape Observatory was originally established 'for the improvement of practical astronomy and navigation'; the Union Observatory was established to provide scientific services and a centre of research for a new state and a rapidly developing industrial area, and has grown with them. But the interior of southern Africa, of which the country round Johannesburg is fairly typical, has quite extraordinary advantages from the astronomical point of view. Its altitude of more than 5000 ft makes an appreciable difference to the absorption of starlight by the atmosphere. The climate is ideal: during half the year the sky is almost completely cloudless, and even during the southern summer, from October to March, when rain does fall, it does so in brief, violent thunderstorms which leave the air washed clean of dust and of an astounding transparency and steadiness. Moreover, all these advantages are to be had in a region from which the relatively very badly explored southern sky is visible.

All these factors have combined to attract astronomers to southern Africa. In 1925 the southern station of the Yale University Observatory was set up by Professor Schlesinger under the direction of Dr Alden in the grounds of the University of the Witwatersrand in Johannesburg. The equipment includes a 26-inch photographic refractor used for the observation of parallaxes and proper motions of southern stars, and this work has been continued under the direction of Professor C. Jackson, now director of the Yale-Columbia station, who as a former member of Innes' staff can in a way be regarded as a scientific grandson of Gill. In 1926 a temporary solar station was set up by the Smithsonian Institution on Mount Bukkaros in South-West Africa, and in the same year the Lamont-Hussey Observatory of the University of Michigan, equipped with a 27-inch visual refractor, was established at Bloemfontein. This city, the capital of the Orange Free State, is some 300 miles south of Johannesburg and at a lower altitude, but the climate and topography are very similar. The refractor, in the hands of Dr Rossiter, has been the means of discovery of many thousands of new double stars.

In the next year the Boyden station of Harvard College Observatory was established at Maaselspoort, a few miles outside Bloemfontein. In 1887 Uriah A. Boyden of Boston had bequeathed a large sum to Harvard for astronomical observations at high altitude, and the bequest was first used for work at Arequipa, Peru. However, the summers there proved almost uniformly cloudy, and in 1927 Dr J. S. Paraskevopoulos brought the station to Bloemfontein. The equipment is elaborate, and includes a reflector of 60-inch diameter, the Bruce 24-inch photographic refractor, and a photovisual refractor of 13-inch aperture. The last instrument has been used with an objective prism for spectroscopic work, while small cameras, of which there are several, are used for regular patrol surveys of the sky. The main function of this station is to supply southern sky material to Harvard Observatory, and, on this, extensive researches on photometry, star distribution, and variable stars have been based.

Over many years, by interchange of visits and in other ways, close relations had been maintained between the Union Observatory in Johannesburg and observatories in Holland, particularly that of Leiden University. Just before the second world war this collaboration was carried a step further when Leiden, aided by a Rockefeller grant, established in the grounds of the Union Observatory a large double refractor of 16-inch aperture. This instrument has been used for photometric work of various types, and recently an electron multiplier apparatus for direct photometry of stars has been installed. The present observer is Dr Wesselink, successor to the late Dr van Gent, who throughout the war had continued work with this telescope.

From November 1931 to March 1933 Leiden had also maintained a station on the equator, in Kenya, at a very high altitude for the purpose of making fundamental determinations of stellar declinations, and a similar station was re-established in 1947. Quite apart from this, which perhaps hardly falls within the ambit of a sketch of astronomy in southern Africa, we have enumerated no fewer than six permanent astronomical stations in the Union of South Africa itself, those at Cape Town, the Michigan and Harvard stations at Bloemfontein, and the Union Observatory, Leiden station, and Yale-Columbia station, all in Johannesburg. In addition mention must be made of a station terminated by the war, established by Breslau University at Windhoek in South-West Africa at an altitude of over 5000 ft, in a climate where the maximum humidity is 40 per cent. and the sky almost completely cloudless at all times. The Union itself is also the scene of considerable amateur astronomical activity, including the private observatory maintained for many years at Lovedale in the Eastern Cape by the late Dr Roberts, where important

pioneer observations of southern variable stars were made.

With the exception of the Union Observatory, all the permanent institutions so far mentioned have represented offshoots or southern stations of previously existing northern-hemisphere organizations. The Radcliffe Observatory at Pretoria, directed by Dr H. Knox Shaw, is the only one which has been transferred from Europe to a better climate and an ampler sphere of activity. Founded in Oxford in the latter part of the eighteenth century out of endowments left by John Radcliffe, principal physician to Queen Anne, the observatory was transferred in 1937 to Pretoria, where the Radcliffe trustees agreed to provide a reflecting telescope of 74-inch clear aperture, the largest in the southern hemisphere. Ill luck dogged the casting of the disk for the main mirror, and work was considerably delayed by the war. Only in 1948 was the completed disk delivered and installed. The telescope, which has a moving weight of 45 tons, is installed in a turret structure on the summit of a ridge overlooking Pretoria. So far it has been used only at the Newtonian focus, and not until very recently has a spectroscope become available. Much of the time of the small staff has been occupied in installation and modification and in bringing new apparatus into use, but even so a considerable amount of work has already been done in direct photography of nebulae, and in the beginnings of surveys of particular classes of interesting objects. An important programme which will be started when the Cassegrain spectrograph becomes available will be the determination of radial velocities of the bright B-type stars (hot blue stars showing a hydrogen spectrum, whose great intrinsic brilliance makes them visible even at a very great distance). The object of this work will be to supplement similar investigations made on northern-hemisphere stars, and its results will enable fundamental data on the rotation of the Milky Way to be derived. It is clear, however, that in addition to this there is an almost unlimited field of galactic and extragalactic objects still to be investigated.

Book reviews

ORGANIC CHEMISTRY FOR EVERYMAN

A Direct Entry to Organic Chemistry, *by John Read. Pp. xiii* + 268. *Methuen and Company Limited, London.* 1948. 4*s.* 6*d. net.*

Professor Read's exceptional talent for explaining intricate chemical subjects to the lay public has probably never been seen to so great advantage as in the present little book. Organic chemistry, of course, is in its main features much more readily comprehensible to the non-scientist than, say, physics or inorganic chemistry, the basic conceptions of its theory being often similar to those of ordinary daily life. For example, the idea of isomerism presents no difficulty to a builder who constructs many different houses out of the same quantities of bricks and tiles. Nevertheless, to lead the novice so far along the path of organic chemistry as to render intelligible to him the mysteries of rubber, penicillin, haematin, Perspex, nylon, fats, camphor, chlorophyll, vitamins, etc., requires not only a mastery of the subject itself but a great facility in exposition—and a shrewd appreciation of human nature. It can occasion no surprise that Professor Read's book has been awarded the Europeo Cortina prize of one million lire for the best popular scientific work published in any language during the past four years. The honour was well deserved and will be generally acclaimed. The book itself is not entirely free from misprints, and the reviewer was surprised that such a polished stylist as Professor Read should use the word 'phenomenal' as equivalent to 'vast.'

FATTY ACIDS

Fatty Acids and Their Derivatives, *by A. W. Ralston. Pp.* 986. *Chapman and Hall Limited, London; J. Wiley and Sons Incorporated, New York.* 1948. 60*s. net.*

There are now a number of books dealing with natural fats—their general occurrence and constitution, their importance in biochemistry and nutrition, and the applications and processing of fats in general (or specific groups or even individual fats) for the various industrial products into which they enter. The present work differs from any of these in that it sets out to give a comprehensive account of all the fatty acids, natural or synthetic, which contain a chain of six or more carbon atoms. At first sight this may seem supererogatory, but the assemblage of data in this field has required a volume of nearly 1000 pages and reference to over 5000 original papers and patents, which are fully annotated. This may serve to indicate that the treatment of the fatty acids as a subject in themselves was worth undertaking, and in Dr Ralston's hands it has been very effectively carried out. It is, of course, largely a book for the specialist. The research worker in this field will find it most useful since it is an almost complete collection of all data, physical and chemical, connected with the fatty acids themselves, their esters, and many of their other derivatives. Chemists concerned in the development of all the fat and soap industries will also find the book of the greatest value. This is not to say that the volume is without interest to the general reader or student; on the contrary, its perusal will convey to them not only the chemistry of the fatty acids, but will give a coherent picture of the different classes of natural

fats and of their transformation into soaps, their hydrogenation to products of specific suitability for different uses, and so on, since all these aspects are touched upon in some detail incidentally to the main objects of the book. The primary objective, however, has clearly been to assemble a complete account, physical and chemical, of the fatty acids and their derivatives, and thus it will find its greatest use among those actively engaged in the study, academic or technical, of fatty products.

T. P. HILDITCH

CHEMISTRY OF COAL

Elements of Coal Chemistry, *by D. J. W. Kreulen. Pp.* 204, *with half-tone and line illustrations. Nijgh and Van Ditmar N.V., Rotterdam.* 1949. *fl*18.25.

In 1935 Dr Kreulen published *Grundzüge der Chemie und Systematik der Kohlen* which was designed to enable students to consult specialized literature on the chemistry of coal and also to present the author's views on various aspects of that subject. The present book is an entirely re-written second edition, and contains 17 chapters ranging from coal classification to the hydrogenation of coal.

The important work of Odén on humic acids is described in detail, while the physico-chemical work on the humic acid curves will repay careful study. Coal bitumens and the micellar structure of coal also receive good treatment within the limits of the space available.

In general the translation has been well done, although there are a few strange words and phrases—which, however, are not confusing. The book contains 51 tables and 70 figures, and the printing and binding are very good. There is no index, but at the end of each chapter numerous literature references are given; these would have been more useful if they had been numbered and indicated in the text. The author has produced an up-to-date and concise survey which should be very helpful to all interested in the subject.

ARTHUR MARSDEN

PLANT PHYSIOLOGY IN HOLLAND

Fifty Years of Plant Physiology, *by Th. Weevers. Pp.* xi + 308. *Scheltema and Holkemas Boekhandel en Uitgevers Maatschappij, N.V. Amsterdam.* 1949. *n.p.*

There is a splendid tradition of plant physiology in Holland, and in recent years Dutch botanists have opened up several new fields of research. Not many English-speaking botanists can read the Dutch language easily, and it is therefore a pleasure to receive from a senior Dutch botanist a summary of plant physiology in Holland over the last fifty years.

For that is what the book is. Notwithstanding its title, it makes no pretence to be history or to cover the whole province of plant physiology. Professor Weevers just talks charmingly about the work of Dutch physiologists and some others. He ably summarizes the state of knowledge up to 1895, and sketches, with the familiarity of a lifetime, the advances made since then, particularly by his own countrymen. And an impressive story it is. Much of the work is already familiar to British plant physiologists, but by no means all. Professor Weevers has so much inside knowledge that facts one knew only from research papers are suddenly illuminated by some comment of his in this book.

In an introduction, Professor F. W. Went suggests that the literal translation lends colour to the book (which it certainly does) and makes it possible to follow more closely the author's meaning (which is unfortunately not true). It is a pity that, in the translation, so much of Professor Weevers' individuality is obscured by a quaint and ambiguous phraseology.

E. ASHBY

VACUUM TECHNIQUE

Scientific Foundations of Vacuum Technique, *by Saul Dushman. Pp.* 882, *with numerous line drawings. John Wiley and Sons Incorporated, New York; Chapman and Hall Limited, London.* 1949. 90*s. net.*

This comprehensive book gives a survey of those fundamental ideas of physics, chemistry, and metallurgy which will be found to be of use to scientists and engineers who are faced with problems which arise in the production, maintenance, and measurement of high vacua. It includes chapters on the kinetic theory of gases and fluid flow; pumps of all varieties; the measurement of low pressures; the interaction of gases with solids, including metals; dissociation and vapour pressures; and rates of evaporation. The wealth of information contained in this book is based on the author's long and distinguished experience in the laboratories of the General Electric Company.

The field of vacuum technique is only as old as the incandescent lamp, yet today it finds applications as diverse as in the smallest receiving valve to a 100 kW transmitter; the synchrotron, betatron, and other high-voltage equipments used in nuclear physics; X-ray tubes of up to two million volts; and liquefiers and other equipment used in low-temperature physics. This treatise should prove to be an invaluable source book and reference book to all who design high-vacuum equipment or use high-vacuum techniques, and all workers in these diverse fields are under an immense debt of gratitude to Dr Dushman for undertaking the task of writing it.

A. R. MILLER

TEXTBOOK OF ZOOLOGY

Traité de Zoologie. Anatomie, Systématique, Biologie, *publié sous la direction de M. Pierre-P. Grassé.* Tome XI: Echinodermes, Stomocordés, Procordés, *par L. Cuénot, C. Dawydoff, P. Brien, C. Drach, etc. Pp.* 1075, *with over* 450 *line diagrams. Masson et Cie., Paris.* 1948. 3800 *francs.*

Volume XI is the first of the 17-volume *Traité* to appear. It covers fossil and living echinoderms, hemichordates and graptolites, tunicates, and cephalochordates. This is a wide field, but although the difficulty of achieving an up-to-date account of each aspect has been overcome by composite authorship, the book remains coherent in plan, and consistent and lively in treatment. Most of the illustrations are excellent, and either original or carefully brought up-to-date, but colours and stereograms seem insufficiently used. The book is clearly printed on good paper.

The morphology and physiology are lucidly expounded, with good summaries; in many cases, e.g. *Amphioxus* nervous system, long-established facts reach a text-book for the first time. Perhaps recent work is overstressed and function deduced from structure not always distinguished from that experimentally demonstrated. Gaps in our knowledge are explicitly stated. The developmental and systematic accounts are excellent, and the inductive reasoning on which different phylogenetic theories are based is clearly visualized. The hemichordates are held, probably correctly, to be closer to the echinoderms and further from the chordates than has been recently assumed.

A revision of these groups has long been needed and this very usable book should be a standard work for many years.

H. P. WHITING

CYBERNETICS

Cybernetics: or Control and Communication in the Animal and the Machine, *by Norbert Wiener. Pp.* 194. *Chapman and Hall Limited, London.* 1949. 18*s. net.*

Cybernetics is a new word, evidently derived from the Greek, meaning to steer. The author of the book under review is Dr Norbert Wiener, a distinguished American mathematician who is a professor at the Massachusetts Institute of Technology, and the subject is automatic controls.

The theory may be said to have begun with Clerk Maxwell's paper of 1868 *On Governors*, in which he discussed mathematically the operation of such contrivances as Watt's governor for steam engines. Now we have innumerable mechanico-electrical systems which are designed to perform quasi-human functions — automatic gyro-compass ship-steering devices, self-propelled missiles which seek their target, and machines for solving elaborate mathematical problems. Many possess sense organs such as photocells or thermometers, and the equivalent of a central nervous system to integrate the transfer of information from their perceptive to their executive elements. Some have even a memory. They lend themselves to description in physiological terms.

The industrial revolution of the last century devalued human strength in comparison with machinery: the pick-and-shovel labourer could not compete with the steam excavator. Will there be a new industrial revolution in which another large group will be thrown out of work by the competition of cybernetic mechanisms?

E. T. WHITTAKER

METALLIC ELASTICITY

Elasticity and Anelasticity of Metals, *by C. M. Zener. Pp. x + 170, with half-tone and line illustrations. University of Chicago Press, Chicago; University Press, Cambridge.* 1948. 22*s.* 6*d. net.*

It is customary in the classical treatment of elasticity to divide the subject into two main sections, the elastic or pre-plastic, in which Hooke's Law is followed, and the non-elastic, which is characterized by the existence of a permanent set. It has, however, been recognized for more than a century that there are departures from Hooke's Law at quite low stress levels, although these deviations were regarded as happy hunting-grounds for the theorist and as not having any particular value for the practising metallurgist. Within the last ten years or so such deviations have assumed great practical value, and the study of them has led to marked advances in our knowledge of the microstructure of solids.

The term 'non-elastic' has attached to itself the connotation of permanent set, and it has been recognized that a new term is necessary to avoid misconceptions. The term 'anelasticity' is therefore formally defined as 'the property of a solid in virtue of which stress and strain are not uniquely related in the pre-plastic range.'

This volume—the first of a series of monographs to be issued by the newly formed Institute of Metals—is an interesting and important contribution to the study of the microstructure of metals, and it can be strongly recommended as a lucid summary of an important branch of the subject of elasticity.

ALLAN FERGUSON

ORGANIC IDENTIFICATION

The Systematic Identification of Organic Compounds, *by Ralph L. Shriner and Reynold C. Fuson. Third Edition. Pp.* 370. *John Wiley and Sons, New York. Chapman and Hall Limited, London.* 1948. 13*s.* 6*d. net*

This work is a stimulating guide to students of chemistry in that section of their university training which, to quote from the authors' preface, 'is the best experience for those preparing for research' whereby they 'are introduced to the methods which it involves.' 'The large amount of research which has been done recently . . . in connection with the preparation of derivatives suitable for characterization' is obvious from chapters VI and VII. References to the literature are numerous, and mostly from the years since 1939. Much emphasis is laid on the mechanism of reaction. Under Schiff's aldehyde test the constitution of the reagent itself and of the compound which results is made clear; modern work on the structure of bisulphite compounds is cited and the student is invited to inquire why cinnamaldehyde combines with two molecules of sodium bisulphite. Mercuration is introduced through a reagent for unsaturated compounds and for aldehydes and ketones, although this subject in general is not surveyed.

Sulphonic acids receive excellent treatment, but the interesting derivatives of the 'chloramine-T' type are omitted, probably because their chief use lies in the formation of sulphilimines from the lesser-known arsines and sulphides. Mercaptans, however, receive consideration.

The mention of the oxonium compounds formed from ketones and esters, and the discussion of the hydrogen bond in relation to physical properties, again reveal a modern outlook.

Practical organic chemistry was never mere 'cookery.' This book reveals it as a fine and inspired art.

FREDERICK CHALLENGER

SEA SHORE BIOLOGY

The Sea Shore, *by C. M. Yonge, F.R.S. Pp. xvi + 311, with numerous coloured plates, half tones, and line drawings. Collins' New Naturalist series, London.* 1949. 21*s. net.*

This is an extremely welcome and attractive book. It is addressed to the general public and is pleasantly and clearly written so as to be readily comprehensible to any reader. It is also of a standard which makes it most valuable to students of biology, and to teachers of the subject whose specialization lies along other lines. It is up-to-date, and has the great advantage of having been written by an author who is thoroughly familiar, at first hand, with the wide field he has covered, and who has had long experience of seashores, not only in Britain but also in other very distant parts of the world. This means that while it deals with the British area, the author's range has been wide enough to enable him to write it against a background of world experience. Thus it contains much of general biological interest. There have been a good many books on the British shores, but this is the best and the most widely informed. The author is much to be congratulated. Another important feature is that the book is illustrated by numerous coloured and monochrome photographs by that outstanding recorder of marine subjects, Dr D. P. Wilson of Plymouth. Many of the plates are excellent, though they are variable in quality, mainly because colour-photography has not advanced quite to the point where an entirely consistent level of success can be expected with close-ups of this type. The best give a most vivid idea of the organisms portrayed, and one (the *Octopus* on plate 17) is magnificent because it combines decorative success with biological appeal.

T. A. STEPHENSON

Notes on contributors

W. H. McCREA,
M.A., B.Sc., Ph.D., F.R.S.E.,

Was born in Dublin in 1904. Sometime scholar and Rouse Ball senior student of Trinity College, Cambridge, and Isaac Newton student of the University of Cambridge. Spent the year 1928–9 at University of Göttingen. Lecturer in Mathematics, University of Edinburgh, 1930–2. Assistant Professor of Mathematics, Imperial College of Science, 1932–6. Professor of Mathematics, Queen's University of Belfast, 1936–44. Professor of Mathematics, University of London (Royal Holloway College), since 1944. War service: Operational research at Admiralty, also work with University Air Squadrons, 1941–5. Secretary of Royal Astronomical Society 1946–9. Keith Prize, Royal Society of Edinburgh, 1941. Author of papers on relativity and astrophysics as well as other branches of mathematics and mathematical physics, and of the books *Relativity Physics* (1935, 1947) and *Physics of the Sun and Stars* (in the press).

T. A. STEPHENSON,
D.Sc.,

Is Professor of Zoology in University College, Aberystwyth. For further details see the October 1947 issue of ENDEAVOUR.

ANNE STEPHENSON

Was always interested in the natural sciences, and after her marriage with Professor T. A. Stephenson in 1922 was trained by him to act as his research assistant. Was a member of the Great Barrier Reef Expedition of 1928–9, during which time she studied the breeding of reef invertebrates; she published a report on this subject in 1934. Was her husband's chief assistant in the ecological survey of the South African coast carried out from Cape Town in 1931–40. Accompanied him to the United States and Canada as co-worker, and has published joint ecological papers with him.

R. DELABY,
D.Sc.

Born in 1891, Pharmacologist (1913), *Docteur ès Sciences* (1923), *Agrégé des Sciences physico-chimiques* at the *Faculté de Pharmacie* in Paris (1926, and Professor in the same establishment from 1937. His researches concern organic synthesis (alcohols and unsaturated aldehydes, triols, sulphonamide-amidines, pyrazolones, etc.), analytical chemistry, hydrology (radioactivity of thermal springs in the upper heights of the Vosges), hygiene, and industrial security. With J. A. Gautier he published *Analyse qualitative minérale à l'aide des stilliréactions.* General Secretary of the Chemical Society of France from 1933 to 1940, he was its president in 1947. Since the end of 1945 he has also been General Secretary of the International Union of Pure and Applied Chemistry.

R. J. GAUTHERET,
D.Sc.,

Was born in 1910 and studied at the Faculty of Science in the University of Paris under the direction of Professor Guilliermond. He was appointed Professor of Plant Biology at the Sorbonne in 1942. His researches are chiefly concerned with plant tissue culture, a subject in which he was one of the first to achieve success. He founded the earliest laboratory entirely devoted to this work and, with the aid of his collaborators, aims at applying the new technique to the solution of various problems of morphology, physiology, and pathology.

MYRON GORDON,
B.S., M.S., Ph.D.

Born in 1899. Educated in New York City High School of Commerce, New York State College of Agriculture, and Cornell University at Ithaca, where he obtained his doctorate in 1929. Organized the fish genetics laboratory at Cornell in 1924 under the joint sponsorship of the departments of plant breeding, aquiculture, and zoology. In 1927 isolated the macromelanophores, and in 1931 announced that these large black pigment cells were essential in the development of melanomas. Fellow of the John Simon Guggenheim Memorial Foundation 1938–40. Since 1940, geneticist of New York Zoological Society, and since 1946 also principal investigator under a grant from the National Cancer Institute of United States Public Health Service on the project *Genetic and Correlated Studies of Normal and Atypical Pigment Cell Growth.* In 1948 edited *The Biology of Melanomas.*

WILSON BAKER,
M.A., D.Sc., F.R.S.,

Was born in 1900 at Runcorn, Cheshire, graduated at the University of Manchester, and carried out research first under Professor A. Lapworth and then under Sir Robert Robinson. He left a position on the staff in 1927 to take up work in the Dyson Perrins Laboratory at Oxford, where he remained till appointed to the chair of Organic Chemistry at the University of Bristol in 1945. He was Fellow and Praelector in Chemistry at the Queen's College, Oxford, from 1936 to 1945. He is the author of many papers on a variety of organic chemical subjects, including plant colouring matters and the effect of hydrogen-bonding on organic molecules, and has more recently become interested in non-benzenoid compounds of essentially aromatic type, a subject dealt with in his Tilden Lecture in 1944.

W. J. ARKELL,
M.A., D.Sc., F.R.S.,

Was born in 1904 at Highworth, Wiltshire, and was educated at Wellington College and New College, Oxford. He has devoted himself to geological research, except during the war years, when he was a member of the staff of the Ministries of Shipping and (later) War Transport. In 1926–30 he worked with Dr K. S. Sandford on Pliocene and Pleistocene problems in Egypt, but most of his work has been on the stratigraphy, palaeontology, and structure of the Jurassic rocks. Besides about eighty scientific papers he has had two monographs on British Jurassic mollusca published by the Palaeontographical Society, and has published four books: *The Jurassic System in Great Britain* (1933), *The Geology of Oxford* (1947), *Oxford Stone* (1947), and *The Geology of Weymouth, Swanage, Corfe and Lulworth* (1947). He has held research fellowships at New College, Oxford (1933–40), and at Trinity College, Cambridge, since 1947. In 1944 he was awarded the Thompson Gold Medal of the United States National Academy of Sciences, and in 1949 the Lyell Medal of the Geological Society of London.

DAVID S. EVANS,
Ph.D., F.Inst.P.,

Has recently taken up an appointment as Second Assistant at the Radcliffe Observatory, Pretoria. For further details see the October 1948 issue of ENDEAVOUR.

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